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AUTOMATED MODEL ATMOSPHERE GENERATOR PROGRAM (AMAG)

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FEBRUARY 1980

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Final Report for Period 10 October 1977 — 31 October 1979

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AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This paper documents a computer program for generating internally consistent model atmosphere data based on a terrain following five-layer temperature model derived from the 1976 U.S. Standard Atmosphere and the 1966 U.S. Standard Atmosphere Supplements. For any given geometric altitude, terrain height, ground level temperature and altimeter setting, the Automated Model Atmosphere Generator (AMAG) program will

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calculate corresponding temperature and pressure altitude values. From these two output parameters the user can compute additional environmental parameters needed to solve particular engineering problems.

FOREWORD

This report documents a computer program called Automated Model Atmosphere Generator (AMAG) which was developed under the auspices of AFSCR 80-7 by the author as Staff Meteorologist to the Aeronautical Systems Division (ASD), Wright-Patterson Air Force Base, Ohio.

The work reported herein was performed during the period 10 October 1977 to 31 October 1979 in support of engineers assigned to the Directorate of Flight Systems Engineering of the Deputy for Engineering of ASD.

The author wishes to thank Mr. Timothy P. Sweeney and Mr. Thomas D. Morgan of ASD/ENFTC for their assistance in the design, review, testing and implementation of the AMAG program at ASD. The author submitted the report in November 1979.

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INTRODUCTION

Certain physics and engineering problems require the use of model or reference atmospheres to represent the environment. Such problems include determinations of engine and aircraft performance, aerodynamic characteristics, skin, compartment and equipment temperatures under transient climb conditions and calculations associated with the vertical ascent and descent of missiles or munitions. These particular model atmospheres must not only be hydrodynamically consistent in the vertical and homogeneous in composition such as in a standard or reference atmosphere but also must be applicable on a worldwide basis. A more complete discussion of standard and reference atmospheres and some definitions of terms used in this report are given in Appendix E. The most common standard atmosphere is the 1976 U.S. Standard Atmosphere (Reference 10). However it only represents idealized, steady-state-conditions near 45° latitude, primarily over land areas and does not accurately represent conditions at any given place or at any given time of year, season, month or day.

Similarly, model atmospheres specifying the vertical envelopes of environmental extremes have been useful in the design of weapon systems to operate under various conditions of temperature, pressure, density, humidity, wind, etc. The most commonly used of these model atmospheres have been the "hot day" and "cold day" atmospheres taken from the Hot and Cold Atmosphere Tables in the 1957 MIL-STD-210A (Reference 6). These tables specified the temperature extremes (hot or cold) expected at various altitudes (levels) from sea level to 100,000 feet. However, they do not accurately estimate conditions likely to be encountered during vertical motion through the atmosphere. These atmospheres were actually constructed to provide an estimate of the ten percent calculated risk for the hottest and for the coldest areas of

the world, level-by-level, without regard to the relationship between levels. Thus the vertical temperature distribution in its entirety as given in either the Hot or Cold Atmospheric Tables will never occur at any given time. For example, in the mid-latitudes, both hot and cold extreme temperatures can occur at the same time at different altitudes over the same location. Thus it was imperative (as stated in MIL-STD-210A) that problems dependent on integrated temperature, pressure and density over an altitude range be solved by using the Polar and Tropical Atmosphere Tables which were also given in MIL-STD-210A. These latter reference atmospheres were both homogeneous and hydrodynamically consistent and represented average January conditions in the polar regions and annual mean conditions in the tropics respectively. However, these did not satisfy the design engineer's need for vertically consistent hot and cold extreme temperature profiles. Thus design engineers continue to use the Hot and Cold Atmospheres from MIL-STD-210A as well as associated terminology, i.e., "Hot Day", "Cold Day" and "Tropical Day". A comparison of the two sets of MIL-STD-210A Atmospheric Tables as depicted in Figure 1 clearly shows how unrealistic the Hot and Cold Atmospheres are when taken in their entirety.

Subsequently the MIL-STD-210A Hot and Cold Atmosphere Tables were replaced in the 1973 MIL-STD-210B (Reference 7) by tables of the 1%, 5%, 10% and 20% high and low temperature extremes with altitude for worldwide operations. These tables likewise do not represent vertically consistent profiles of the atmosphere and are strictly envelopes of level-by-level extreme conditions. Thus they should not be used to consider the total influence of the atmosphere on a weapon system or piece of equipment during its trajectory. For such applications and in lieu of the MIL-STD-210A Polar and Tropical Atmosphere Tables, MIL-STD-210B recommends the use of the annual tropical atmosphere, and winter (January) and summer (July) atmospheres for each

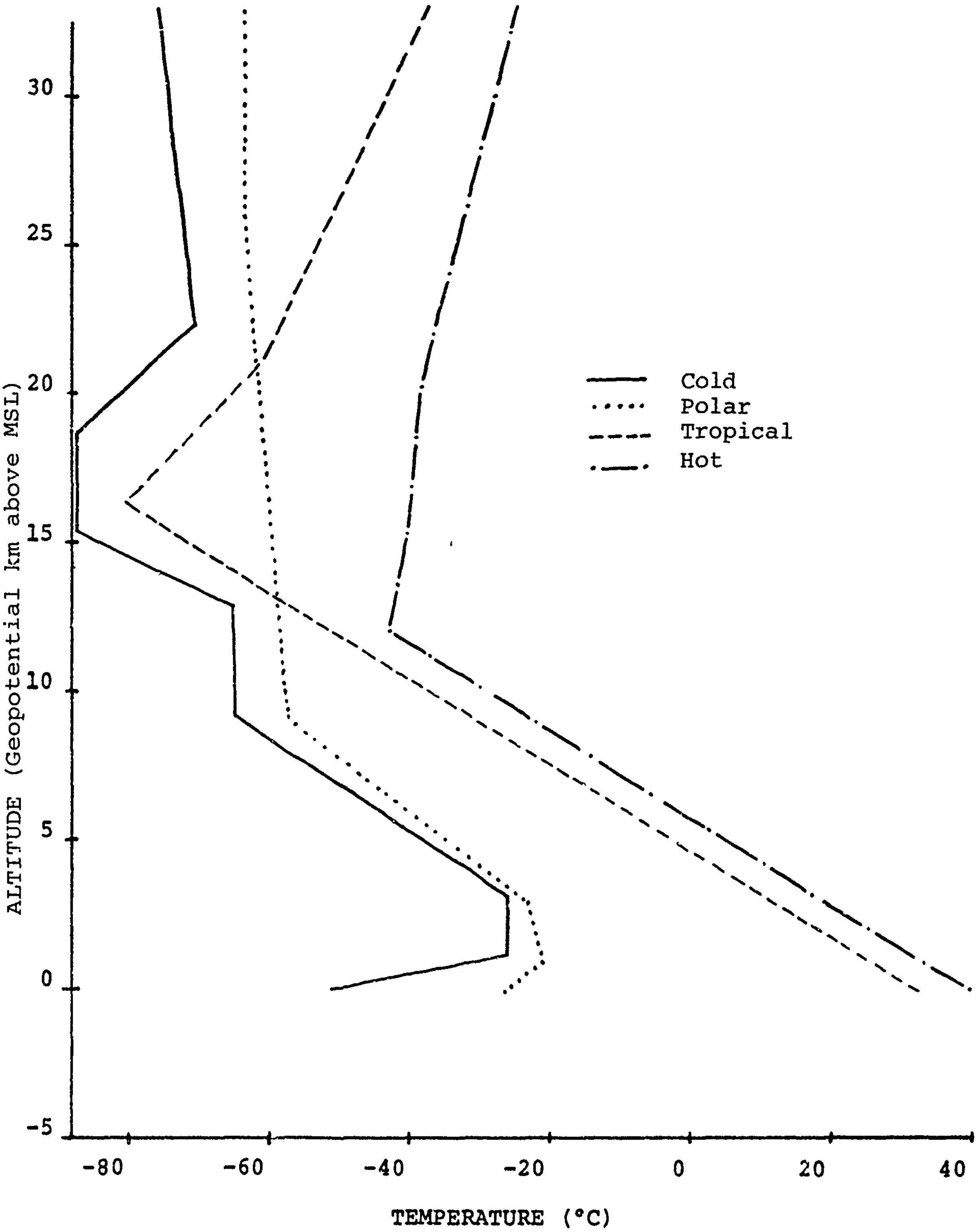

Figure 1. Comparison of MIL-STD-210A Hot, Cold, Polar and Tropical Atmospheres

15° latitudinal band outside the tropics, as published in the "U.S. Standard Atmosphere Supplements, 1966" (Reference 9). Although these atmospheres are vertically consistent, it is sometimes difficult to select which one(s) to use in a particular situation. They are also somewhat inconvenient for the design engineer to use in a computer environment. Moreover, since these atmospheres represent seasonal mean atmospheres they do not provide truly extreme hot or cold day temperature profiles. Such latter profiles normally only occur for a few hours of the day and only affect the lowest part of the atmosphere in the hottest (coldest) areas of the world. Thus neither a hot day profile in the tropics nor a cold day profile in the polar region can be represented by means of data taken over all hours of the day for all days of a season. However, such "Hot Day" and "Cold Day" profiles are of use to weapon systems design engineers as is evidenced by their continued consideration of the MIL-STD-210A Hot and Cold Atmosphere Tables.

This has also led to the use of other unrealistic model atmospheres such as the constant-departure-from-standard vertical temperature profile models found in some aircrew flight simulator software. Such vertical temperature models are not only improbable but also become unrealistic when hot or cold temperature extremes are desired, especially over high surface terrain heights. Similar problems occur when engineers try to use test range reference atmospheres as design criteria. Such atmospheres are usually constructed in table form from annual or monthly means of data taken at standard pressure levels throughout all hours of the day. In addition, tables of extremes at various levels will be provided. For certain high altitude ranges, table values may also include data for levels below the height of the range. Such data may be unrealistic, particularly if it was generated bv downward linear extrapolation of range surface data values. Thus range reference atmospheres do not provide the engineer with vertically consistent extreme temperature profiles.

As a result, a computer program has been written to provide engineers and simulator software designers with a simple means to generate model reference atmospheres in which the above deficiencies are resolved. Reference atmospheres can now be generated for various geographic latitudes by varying the input ground level temperature and sea level pressure values. These atmospheres are not only homogeneous and hydrodynamically consistent but also can incorporate hot or cold ground temperature extremes as well as terrain height. The algorithms, assumptions and meteorological basis in the development of this program are discussed in Section II.

SECTION II
PROGRAM DESCRIPTION

Given a geometric altitude, a terrain height, a ground level temperature and an altimeter setting (sea level pressure in inches of Hg), the AMAG program will compute a corresponding internally consistent pressure altitude and ambient air temperature. From this output the user can calculate most of the environmental parameters needed to solve particular engineering problems. For computational purposes all temperatures are considered to be virtual temperatures. An extensive list of such parameters and the appropriate equations for calculating them are provided in Appendix B.

This program's terrain following feature requires the input of a terrain height and a ground level temperature. However, if a terrain height of zero is input, the ground level temperature then becomes a sea level temperature. When the standard sea level temperature (15°C), zero terrain height and standard sea level pressure (29.92 In. Hg) are the inputs, the output will be the 1976 U.S. Standard Atmosphere temperature and pressure altitude for any given geometric altitude. The allowable range of geometric altitude is from -2.0 km to 32.0 km. The program considers the difference between geometric altitude and geopotential altitude to be negligible since for aeronautical purposes (altitudes below 33 km) this difference is very small (a maximum difference of 0.5% at 33 km). This program assumes that the air behaves as a perfect gas, is completely homogeneously mixed and is in hydrostatic equilibrium. The allowable range of terrain height is from -2.0 km to 5.9 km. The allowable range of input ground level temperatures is from -50.0°C to 60.0°C. Mean Sea Level (MSL) corresponds to the effective value of the earth's radius (6356.766 km) at which the acceleration of gravity equals 9.80665 m/s^2 and where the geometric altitude equals zero geopotential km. A unique feature of this program is that both terrain and geometric heights below sea level are allowed as well as geometric heights below the terrain height. This feature was included to allow independency and

flexibility in selecting input geometric and terrain height values. For example, if this program was used in real-time aircrew flight simulator software, this program would not cause the main program to "error off" when the aircraft geometric height was below the terrain height.

The program uses a terrain following five-layer vertical temperature model based on the 1976 U.S. Standard Atmosphere and the 1966 U.S. Standard Atmosphere Supplements. The model contains a 2 km thick ground radiation boundary layer and a tropopause whose height and temperature vary according to the input ground level temperature. This allows the user to specify very hot or very cold ground temperatures typically found in the tropics or arctic regions respectively. The vertical temperature profile is constructed from the ground up by calculating the temperatures at the base and the top of the lowest layer and of each layer in sequence. The program only constructs as much of the vertical profile as is necessary to compute the temperature and the pressure altitude at the required geometric altitude. Within each layer, a constant lapse rate of temperature is assumed. Thus the temperature at a given height can be calculated either by linear interpolation with height between the temperatures for the base and the top of the layer or by upward linear extrapolation with height of the layer's base level temperature using a predetermined vertical temperature lapse rate.

The pressure altitude is also calculated from the ground up by correcting the geometric altitude for the variation of the input sea level pressure (altimeter setting) and for the deviation of the vertical temperature distribution from that assumed in the standard atmosphere. For the latter correction, the mean temperature of each layer is compared to the mean temperature of that layer in the standard atmosphere. The corrected thickness values for each layer are then added together to arrive at the pressure altitude.

SECTION III
PROGRAM DESIGN AND SPECIFICATIONS

The construction of the AMAG model's various layers as depicted in Figure 2 is as follows:

a. The first and lowest layer is the terrain layer which is bounded at the bottom by -2.0 km and at the top by the input terrain height (ground level). The temperature everywhere within this layer is set equal to the input ground level temperature. The portion of the terrain layer that is below sea level is not considered in the pressure altitude computations except when the geometric height is both below sea level and below the terrain height.

b. The second layer is a 2 km constant thickness terrain following radiation boundary layer. The base of this layer is the top of the terrain layer at which the temperature is the input ground level temperature. The method of calculating the temperature at the top of this layer is rather empirical in nature, based on the author's experience and on the need to account for both hot and cold ground level temperature extremes. This method is described as follows:

(1) In this program it is assumed that all ground level temperature extremes (those less than 0°C or greater than 30°C) are related to an excess or deficit of surface heating and are confined to the lowest 2 km above ground level. The need for a simple linear vertical temperature lapse rate model within this radiation boundary layer led to the choice of 2 km as its thickness. The 2 km value, although seemingly high, is borne out in the model reference atmospheres contained in the 1966 U.S. Standard Atmosphere Supplements (See Figures 3, 4, and 5). Furthermore, between 2 km and 8 km, the vertical temperature profiles for these latter atmospheres tend to depart only by 15°C at the most from the 1976 U.S. Standard Atmosphere and also have comparable tropospheric vertical temperature lapse rates.

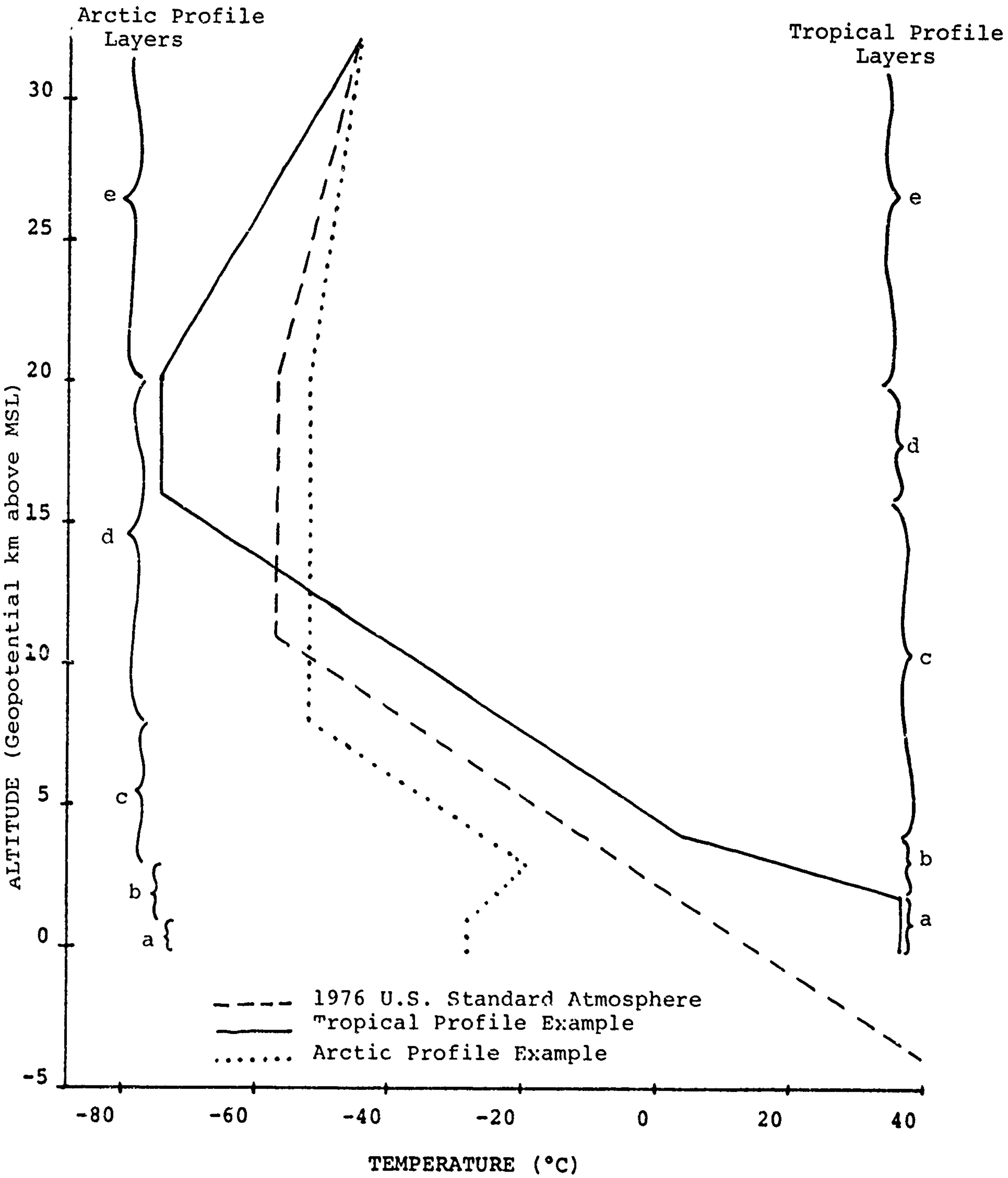

Figure 2. AMAG Model Atmosphere. Layers in example profiles are labeled according to the corresponding paragraphs in Section III of the text which describe their derivation.

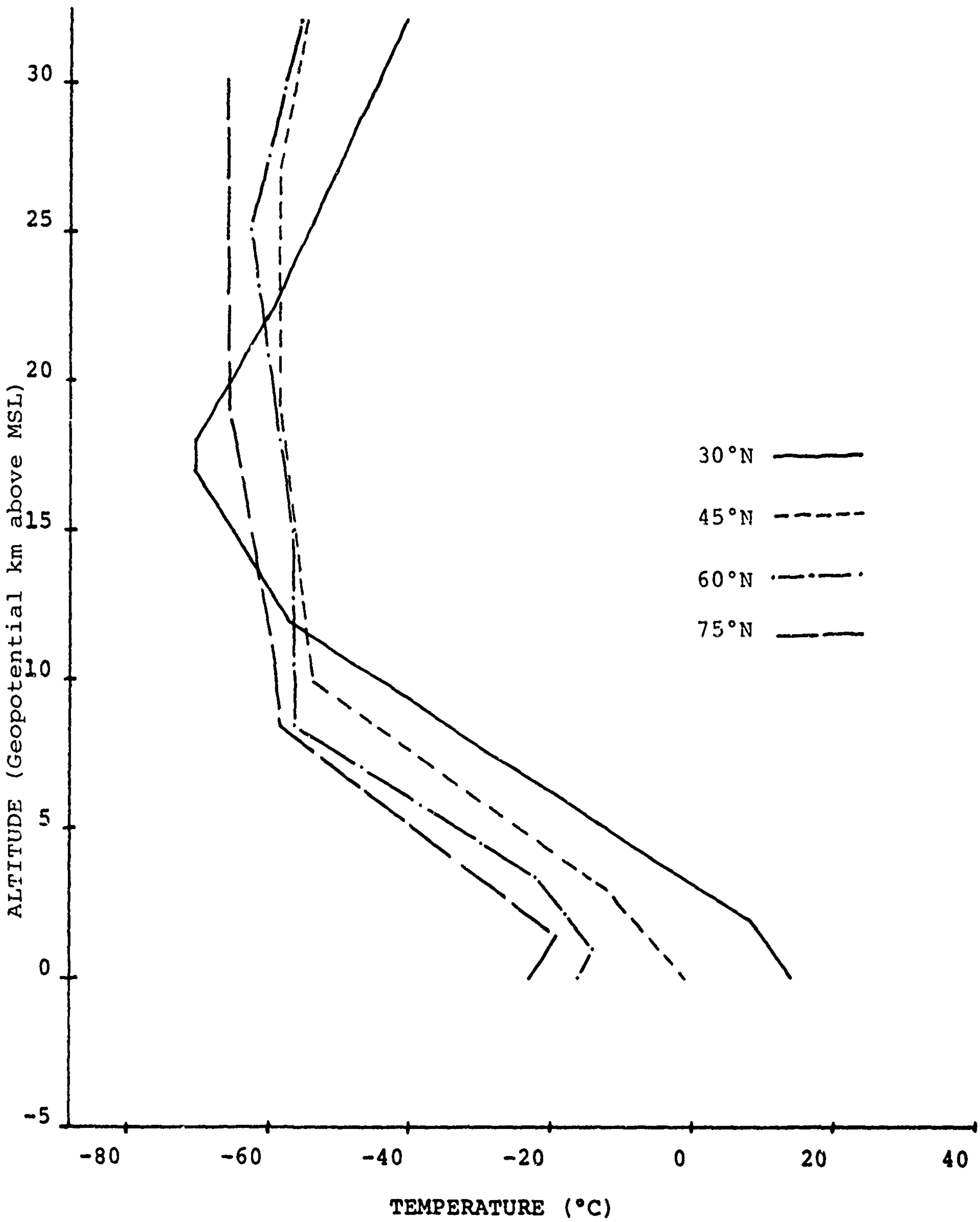

Figure 3. U.S. Standard Atmosphere Supplements, 1966 (January)

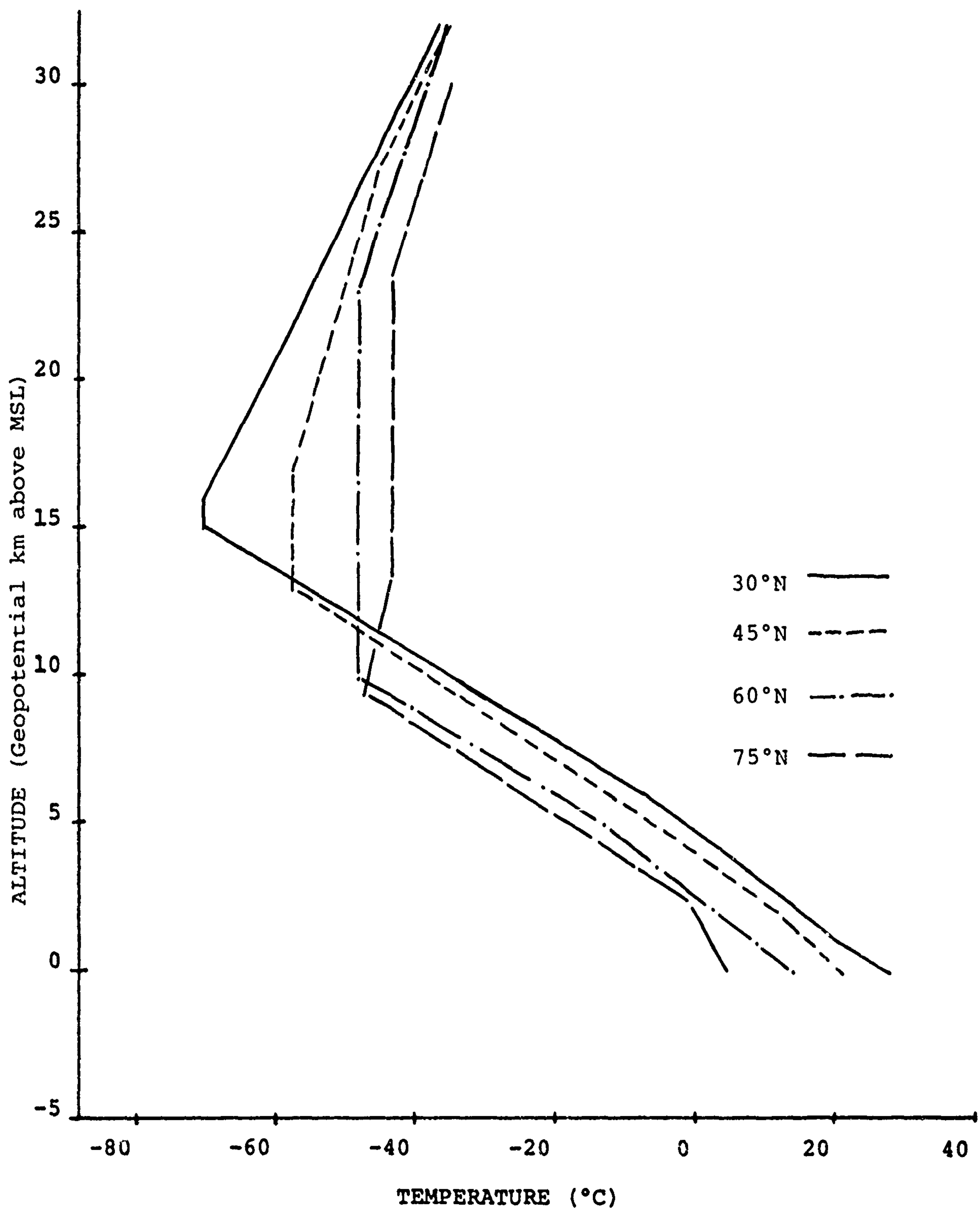

Figure 4. U.S. Standard Atmosphere Supplements, 1966 (July)

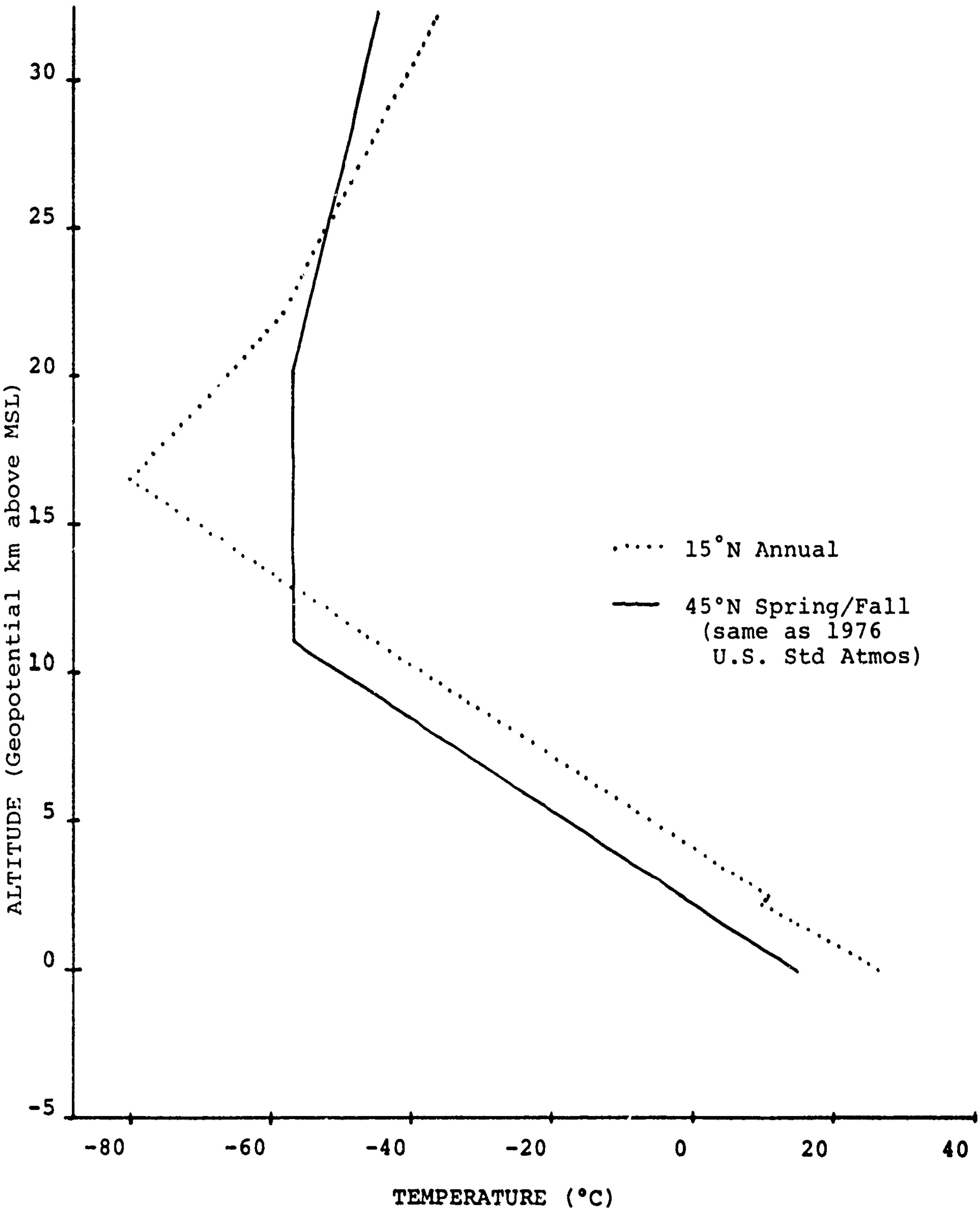

Figure 5. U.S. Standard Atmosphere Supplements, 1966 (Annual)

The magnitude and algebraic sign of this departure appear to be a function of the difference between the sea level temperature and the standard atmosphere sea level temperature of 15°C. Thus, for this model, it is assumed that sea level temperatures less than 0°C or greater than 30°C are extremes and that the 2 km boundary layer provides a simple method for connecting such extremes to the 2 km height where the vertical temperature lapse rate then becomes equal to that of the standard atmosphere. From a physical point of view, 2 km is the upper limit of surface boundary layer friction and diurnal temperature effects.

(2) To relate the model's ground temperature input to a sea level temperature requires the calculation of an "equivalent" sea level temperature. When the terrain height is zero or positive, this temperature equals the ground level temperature. However, if the ground level temperature is greater than 30°C, then the "equivalent" sea level temperature is set equal to 30°C. Likewise, if the ground level temperature is less than 0°C, the "equivalent" sea level temperature is set equal to 0°C. When the terrain height is negative, the "equivalent" sea level temperature is calculated by extrapolating the ground temperature upward to sea level using the standard atmosphere lapse rate and then correcting as necessary for low or high extremes to 0°C or 30°C respectively. The temperature at the top of the 2 km boundary layer is then calculated by extrapolating the "equivalent" sea level temperature upwards or downwards using the standard atmosphere lapse rate. Temperatures at any level within this 2 km boundary layer can be calculated by linear interpolation with height between the temperatures at the top and at the bottom of the layer.

c. The third layer is bounded at the bottom by the top of the boundary layer and at the top by the model's tropopause. Within this tropospheric layer, the temperature lapse rate is always equal that of the standard atmosphere. The height of the top of this layer is a function of the height of the tropopause. Here it is assumed that cold sea level temperatures are associated with a low altitude warm tropopause and warm sea level

temperatures are associated with a high altitude cold tropopause. Empirical formulas were derived to calculate the tropopause height and temperature directly from the model's "equivalent" sea level temperature. These formulas interpolate linearly between those values for the tropopause heights and the tropopause temperatures which are assumed to be associated with the "equivalent" sea level temperatures of 0°C, 15°C, and 30°C. Thus, for 15°C the standard atmosphere tropopause height and temperature values of 11 km and -56.5°C are assumed. For 30°C the values used are 16 km and -74°C and for 0°C, they are 8 km and -52°C. These specific values were chosen for simplicity and to mesh perfectly with their coincident "equivalent" sea level temperatures using the standard atmosphere lapse rate. These values also reasonably fit annual averages of corresponding values given in the 1966 U.S. Standard Atmosphere Supplements and facilitate the output of the 1976 U.S. Standard Atmosphere when standard sea level conditions are used as input. The temperature at any level within this layer can be calculated by linear interpolation with height between the temperature values computed at the bottom and at the top of this layer.

d. The fourth layer is bounded at the bottom by the tropopause and at the top by a fixed height of 20 km. This layer represents the lower stratosphere and has an isothermal temperature profile. The temperature at any level within this layer is equal to the tropopause temperature which is calculated from the "equivalent" sea level temperature. The latter is also used to calculate the tropopause height. The value of 20 km as the height of the top of this layer is the same as that used in the 1976 U.S. Standard Atmosphere.

e. The fifth layer represents the upper stratosphere and is 12 km thick, extending from 20 km to 32 km. The layer's upper boundary height and temperature values are the same as those used in the 1976 U.S. Standard Atmosphere, i.e., 32 km and -44.5°C respectively. With the layer's lower boundary height fixed at 20 km and its temperature equal to the tropopause

temperature, the temperature at any level within this layer can be calculated by linear interpolation with height. The temperature lapse rate in this layer is thus a function of the tropopause temperature or in reality a function of the "equivalent" sea level temperature.

The temperature profiles for 4 specific cases as calculated by the AMAG Program are depicted in Figures 6 and 7. Specific input data values for each case are provided in the figure legends. It should be noted that the AMAG program does not actually calculate complete vertical profiles but only computes one temperature value and one pressure altitude value corresponding to one input geometric height. A vertical profile of temperature and pressure altitude could be generated by placing the subroutine AMAG calling statement in an iterative loop involving geometric height. However, one should be very careful about interpolating between output values since the input geometric heights may not correspond to the model atmosphere's breakpoint temperature heights. In these cases it would be better to use the desired geometric heights directly as inputs.

Some caution should be used when interpreting the results of this model when the surface temperature inputs are extremes within a given latitudinal band. This model (particularly the tropopause algorithm) was basically designed to simulate the mean annual temperature profiles (± one standard deviation) for various latitude bands such as those given in the 1966 U.S. Standard Atmosphere Supplements. Thus, for example, the model cannot always simulate representative atmospheres for either a very cold day in the subtropics or for a very hot day in the arctic. Likewise, diurnal temperature effects are not actually accounted for. However the model will produce profiles very similar to the MIL-STD-210A polar and tropical atmospheres. See Figure 8 for a comparison of this. In Figure 9 the model profiles are also compared to constant-departure-from-standard temperature profiles.

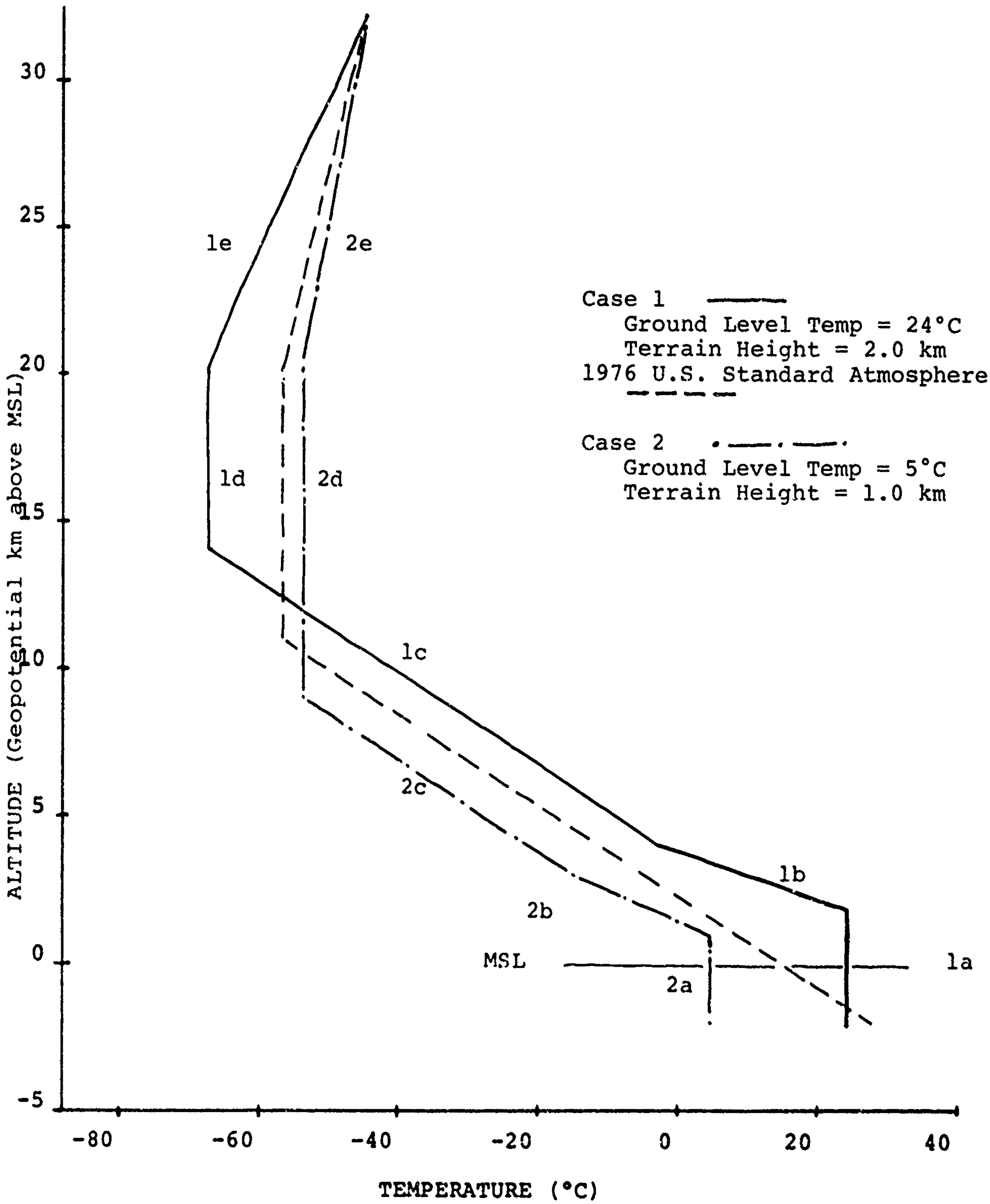

Figure 6. Example AMAG Profiles for Positive Terrain Elevations

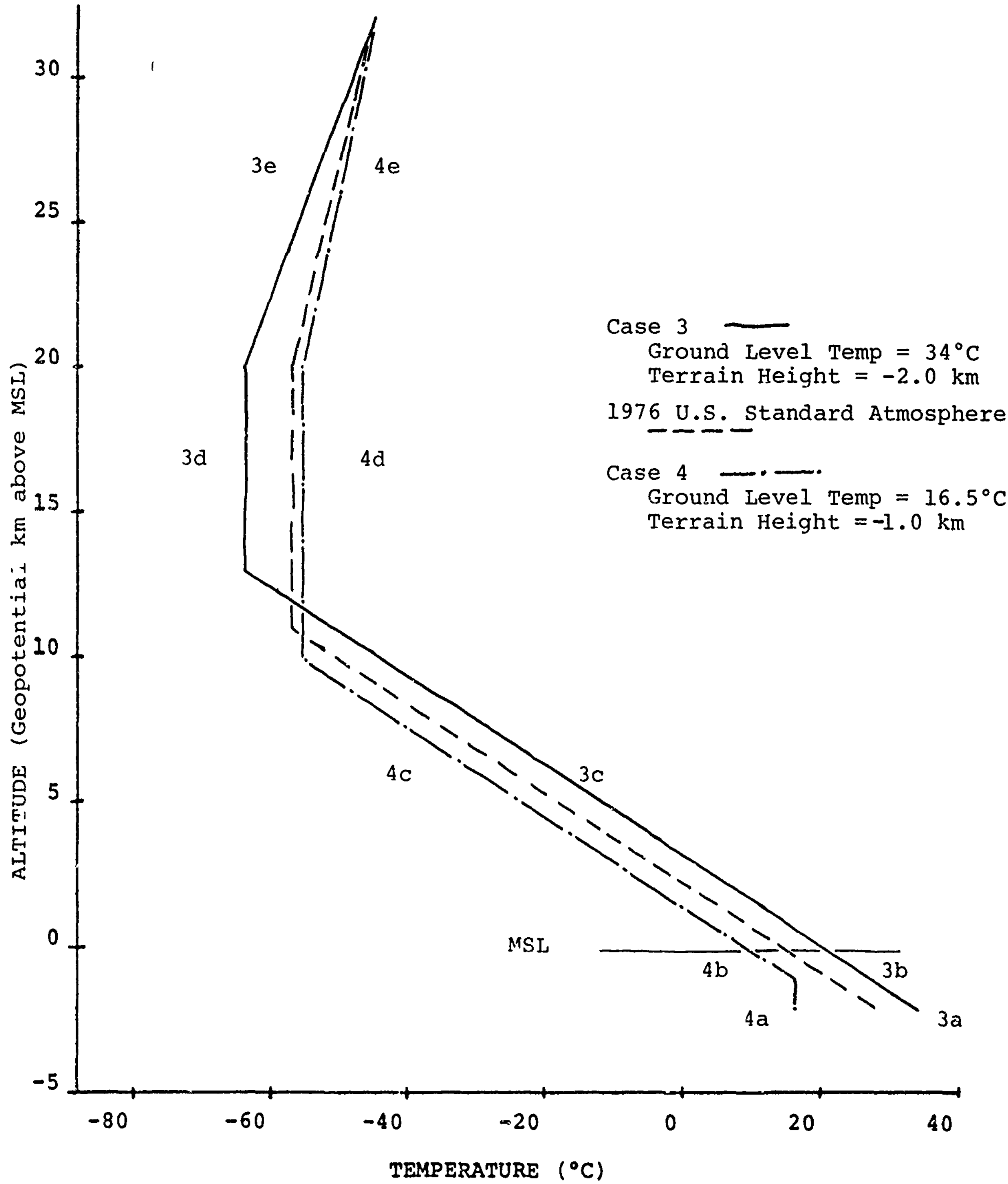

Figure 7. Example AMAG Profiles for Negative Terrain Elevations

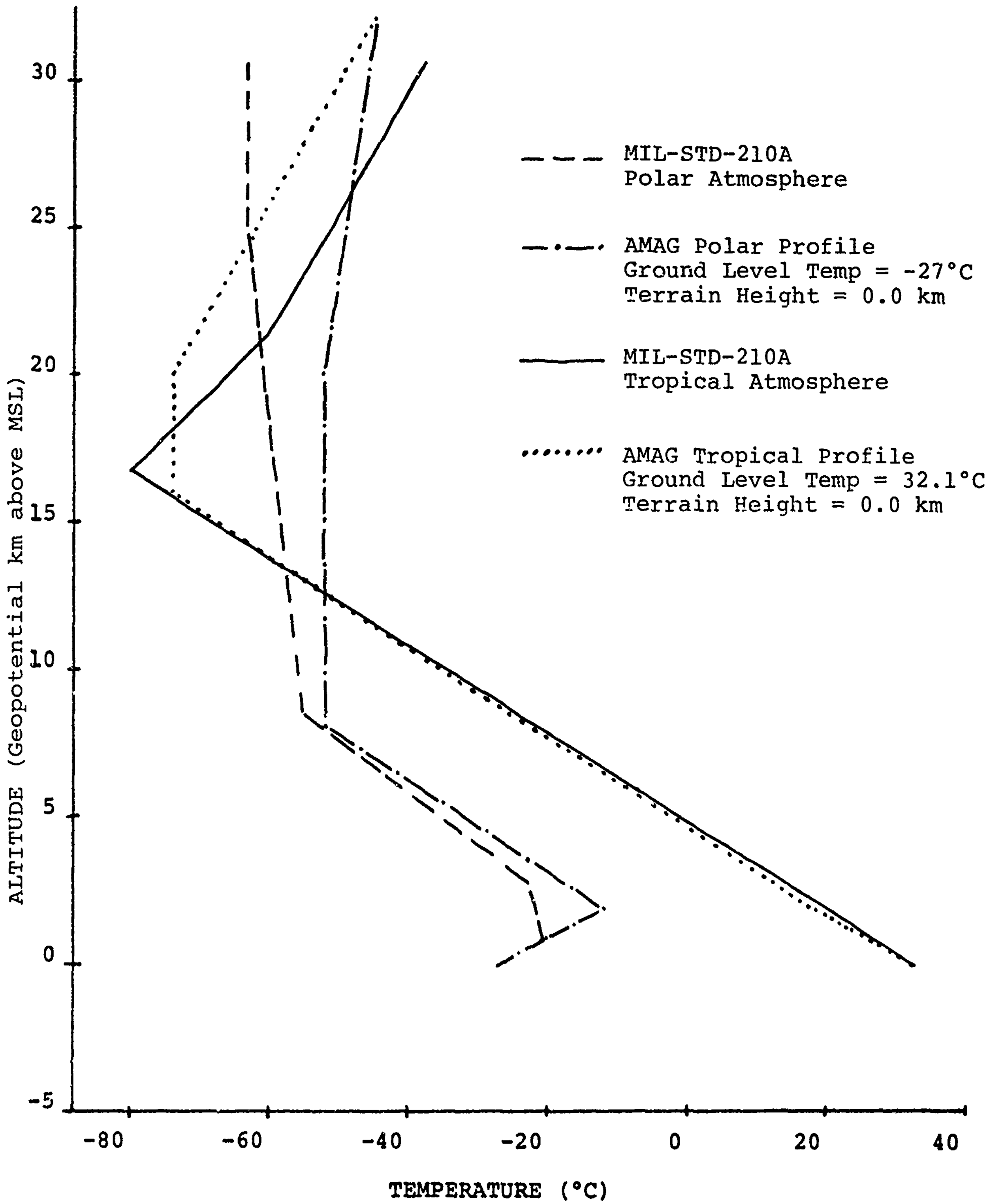

Figure 8. Comparison of MIL-STD-210A Tropical and Polar Atmospheres with AMAG Profiles (generated using the formers' sea level conditions as input)

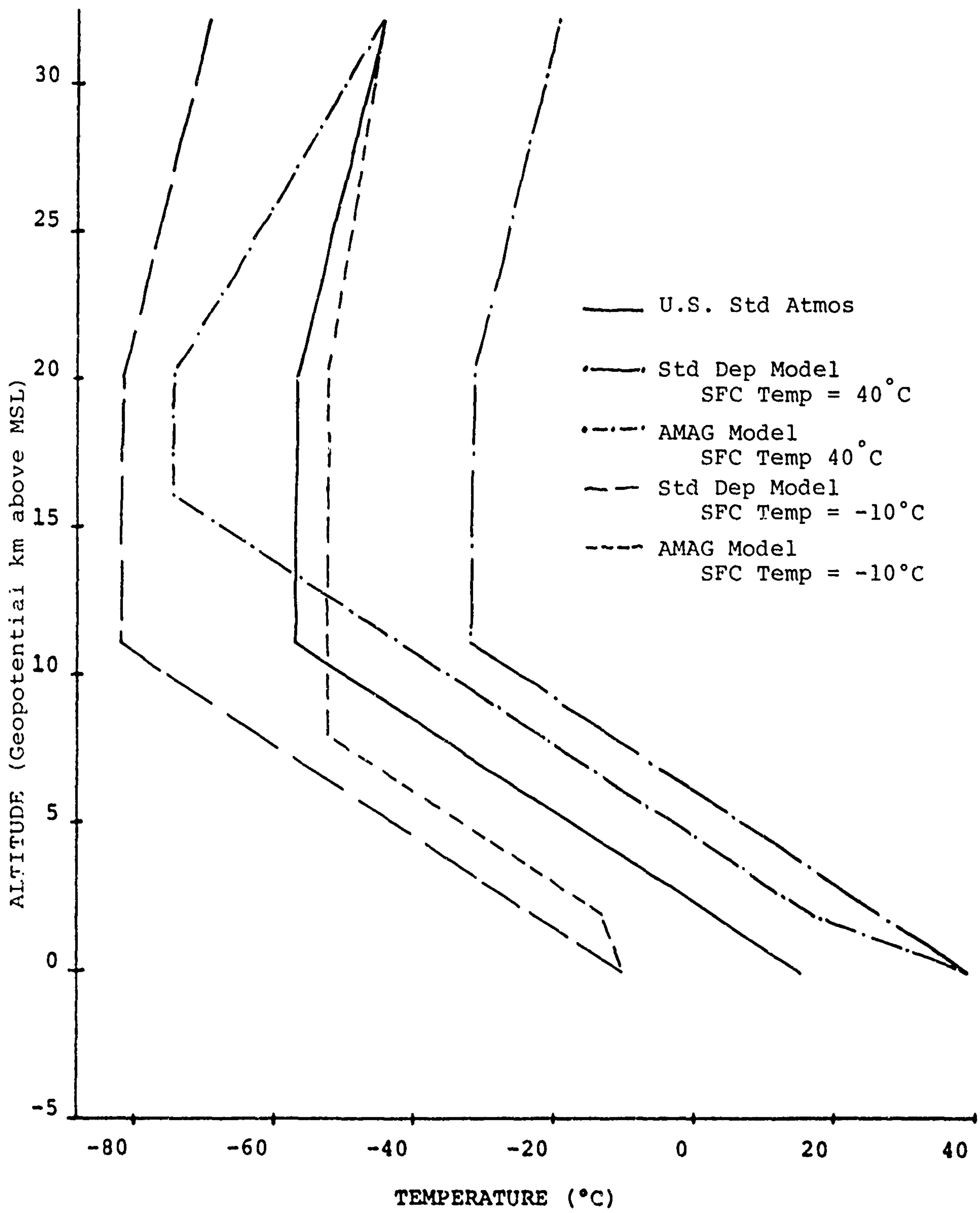

Figure 9. Comparison of AMAG Model to a Constant-Departure-from-Standard Atmosphere Model U.S. Std Atmosphere

SECTION IV
PROGRAM COMPUTER CODE

The AMAG program has been written as a subroutine in Fortrain IV language. The actual program listing and flow chart are given in Appendix A. The program uses °C, feet and In. Hg as units of temperature, height, and pressure respectively but can easily be modified to use either metric or English or British Engineering units exclusively.

Execution time for 5000 calls to a compiled version of this subroutine on a CDC Cyber 175 is approximately one second. Program length on the CDC Cyber 175 is 313 60-bit words.

Questions concerning this code should be addressed to the ASD Staff Meteorology Office (ASD/WE), Wright-Patterson AFB, OH 45433.

SECTION V
PROGRAM APPLICATIONS

The AMAG program output parameters of pressure altitude and virtual temperature can be used to calculate most environmental parameters of use to design engineers. The equations necessary to do this are given in Appendix B.

Additionally, by assuming a generalized atmospheric vertical moisture model, the AMAG output virtual temperatures can be converted into realistic temperature and associated mixing ratios (absolute humidity). The appropriate equations for doing this are given in Appendix C.

Furthermore, Appendix D describes a synthetic vertical atmosphere scalar wind profile model. In this model the jet stream height is made to be consistent with the AMAG tropopause height and a specified surface wind input.

This AMAG program currently is limited to geometric altitudes below 32 km. With minor changes to the program computer code, it can be extended to 47 km geometric altitude.

SECTION VI
CONCLUSIONS

The AMAG program has been tested under a variety of input conditions. The results show that AMAG can reproduce exactly the 1976 U.S. Standard Atmosphere and good fits to the U.S. Standard Atmosphere Supplements, 1966 (MIL-STD-210B) as well as the MIL-STD-210A Polar and Tropical Atmospheres and several test range reference atmospheres.

Within the limitations and assumptions required to develop a simple universal program of practical use to engineers, the AMAG program can be successfully applied to many meteorological, physics and engineering problems including simulation.

Furthermore, it is believed that this program can bridge the gap existing between the MIL-STD-210A and MIL-STD-210B model atmospheres.

APPENDIX A

PROGRAM LISTING AND FLOW CHART

```
      SUBROUTINE AMAG (ZHGT,THGT,TTMP,ALTSTG,ZTMP,ZPA,IER)
C
C***********************************************************************
C
C
C  PURPOSE ---
C     GIVEN A GEOMETRIC HEIGHT *ZHGT* IN FEET, A TERRAIN HEIGHT *THGT*
C     IN FT,A TERRAIN TEMPERATURE *TTMP* IN DEGREES C AND AN ALTIMETER
C     SETTING *ALTSTG* IN INCHES OF HG, THIS PROGRAM USES AN EMPIRICALLY
C     DERIVED MODEL ATMOSPHERE TO COMPUTE THE APPROXIMATE TEMPERATURE
C     *ZTMP* IN DEGREES C AND THE PRESSURE ALTITUDE *ZPA* IN FEET.  BOTH
C     TERRAIN AND GEOMETRIC HEIGHTS BELOW SEA LEVEL AND ALSO GEOMETRIC
C     HEIGHTS BELOW THE TERRAIN HEIGHTS ARE UNIQUELY ALLOWED.
C
C  VARIABLE DESCRIPTION ---
C     VARIABLE  TYPE   I/O/C   DEFINITION AND PURPOSE OF PROGRAM VARIABLE
C       IER     INT.   OUTPT   EQUALS 0 IF NO INPUT ERROR, OTHERWISE ERROR
C       ALTSTG  S.P.   INPUT   ALTIMETER SETTING IN INCHES OF HG
C       THGT    S.P.   INPUT   TERRAIN HEIGHT IN FEET
C       ZHGT    S.P.   INPUT   GEOMETRIC HEIGHT ABOVE MEAN SEA LEVEL IN FT
C       TTMP    S.P.   INPUT   TERRAIN TEMPERATURE IN DEGREES C
C       ZPA     S.P.   OUTPT   PRESSURE ALTITUDE IN FEET
C       ZTMP    S.P.   OUTPT   AMBIENT TEMPERATURE IN DEGREES C
C       W1      S.P.   CALC.   STANDARD ATMOSPHERE TEMPERATURE IN DEG C
C       W2      S.P.   CALC.   EQUIVALENT SEA LEVEL TEMPERATURE IN DEG C
C       W3      S.P.   CALC.   GEOMETRIC HEIGHT ABOVE 65616.8 FEET IN FEET
C       W4      S.P.   CALC.   MAXIMUM HEIGHT ABOVE BOUNDARY LAYER IN FEET
C       W5      S.P.   CALC.   GEOMETRIC HEIGHT ABOVE TERRAIN HEIGHT IN FT
C       W6      S.P.   CALC.   GEOMETRIC HEIGHT OF TOP OF BOUNDARY LAYER
C       W7      S.P.   CALC.   TROPOPAUSE TEMPERATURE IN DEGREES C
C       W8      S.P.   CALC.   ZTMP IN DEGREES K
C       W9      S.P.   CALC.   STANDARD ATMOSPHERE TEMPERATURE W1 IN DEG K
C       W10     S.P.   CALC.   BAROMETER HEIGHT IN FEET
C       W11     S.P.   CALC.   GEOMETRIC HEIGHT OF TROPOPAUSE IN FEET
C       W12     S.P.   CALC.   TERRAIN TEMPERATURE TTMP IN DEGREES K
C       W13     S.P.   CALC.   STANDARD ATMOSPHERE TEMPERATURE AT TOP OF
C                              TERRAIN LAYER IN DEGREES K
C       W14     S.P.   CALC.   AVERAGE STANDARD ATMOSPHERE TEMPERATURE FOR
C                              SEA LEVEL AND TOP OF TERRAIN LAYER
C       W15     S.P.   CALC.   EQUIVALENT SEA LEVEL TEMPERATURE W2 IN DEGK
C       W16     S.P.   CALC.   STANDARD ATMOSPHERE TEMPERATURE AT TOP OF
C                              BOUNDARY LAYER IN DEGREES K
C       W17     S.P.   CALC.   TEMPERATURE AT TOP OF BOUNDARY LAYER IN
C                              DEGREES K
C       W18     S.P.   CALC.   TROPOPAUSE TEMPERATURE W7 IN DEGREES K
C       W19     S.P.   CALC.   MAXIMUM OF GEOMETRIC HGT VS TERRAIN HGT
C       W20     S.P.   CALC.   MINIMUM OF W5 VS 2 KM
C       W21     S.P.   CALC.   MINIMUM OF ZHGT VS W11
C       W22     S.P.   CALC.   MINIMUM OF ZHGT VS STD ATMOS TROPOPAUSE HGT
C
C  INPUT AND OUTPUT REQUIREMENTS ---
C     INPUT THROUGH ARGUMENT LIST
C     OUTPUT THROUGH ARGUMENT LIST
C
C  RESTRICTIONS ---
C     ZHGT MUST LIE BETWEEN -6560. AND 104987. FEET
C     THGT MUST LIE BETWEEN -6560. AND 19357. FEET
```

```
C        TTMP MUST LIE BETWEEN -50.0 AND 60.0 DEGREES C
C        ALTSTG MUST LIE BETWEEN 28.00 AND 31.00 INCHES OF HG
C
C     ERROR CONDITIONS AND RETURNS ---
C        IER=1 IF ZHGT IS OUTSIDE ALLOWABLE RANGE
C        IER=2 IF THGT IS OUTSIDE ALLOWABLE RANGE
C        IER=4 IF TTMP IS OUTSIDE ALLOWABLE RANGE
C        IER=8 IF ALTSTG IS OUTSIDE ALLOWABLE RANGE
C        IF IER>0, PROGRAM RETURNS IMMEDIATELY WITH IER=SUM OF IER VALUES
C
C     ACCURACY ---
C        TEMPERATURE IS ACCURATE TO WITHIN 1 DEGREE C AND PRESSURE ALTITUDE
C        TO WITHIN 100 FEET
C
C     REFERENCES ---
C        U.S. STANDARD ATMOSPHERE, 1976
C        1966 U.S. STANDARD ATMOSPHERE SUPPLEMENTS
C        ASD-TR-79-5056 --AUTOMATED MODEL ATMOSPHERE GENERATOR PROGRAM
C              (AMAG) -- OCT 1979
C
C     LANGUAGE ---
C        FORTRAN IV
C
C     CORE STORAGE --- LESS THAN 320 WORDS DECIMAL
C
C     DISK, DRUM OR TAPE REQUIREMENTS --- NONE
C
C     EXECUTION TIME --- 1.0 SEC FOR 5000 CALLS
C
C     PREREQUISITE PROGRAMS/SUBROUTINES --- AMAX1 AND AMIN1 FUNCTIONS
C
C     MACHINE DEPENDENCE --- NONE
C
C     PRECISION --- SINGLE
C
C     ADDITIONAL ENTRY POINTS --- NONE
C
C***********************************************************************
C
C     OUTPUT DATA INITIALIZATION
C
      ZPA = 0.0
      ZTMP = 0.0
      IER = 0
C
C     INPUT DATA ERROR CHECK
C
      IF (ZHGT.LT.-6560..OR.ZHGT.GT.104987.) IER = IER + 1
      IF (THGT.LT.-6560..OR.THGT.GT.19357.) IER = IER + 2
      IF (TTMP.LT.-50..OR.TTMP.GT.60.) IER = IER + 4
      IF (ALTSTG.LT.28.00.OR.ALTSTG.GT.31.00) IER = IER + 8
      IF (IER) 10,10,99
C
C     CALCULATE STANDARD ATMOSPHERE TEMPERATURE W1 USING THE STD ATMOSPHERE
C     LAPSE RATE OF 0.0019812 DEGREES C /FOOT, TROPOPAUSE TEMPERATURE OF
C     -56.5 DEG C + TROPOPAUSE HEIGHT OF 36089.237 FEET
C
```

```
C  CALCULATE HEIGHT ABOVE 65616.796 FEET
C
   10 W3 = AMAX1(0.0,ZHGT-65616.796)
      W1 = 15. - AMIN1(71.5,0.0019812*ZHGT) + (0.0003048*W3)
C
C  CALCULATE BAROMETER HEIGHT OR HEIGHT OF STANDARD ATMOSPHERE SEA LEVEL
C  PRESSURE SURFACE
C
      W10 = 930. * (29.92 - ALTSTG)
C
C  CHECK IF STANDARD ATMOSPHERE TEMPERATURE DESIRED.
C
      IF (THGT.EQ.0.0.AND.TTMP.EQ.15.) GO TO 15
C
C  CALCULATE EQUIVALENT SEA LEVEL TEMPERATURE W2 (SEE BASIC REFERENCE)
C
      W2 = TTMP
      IF (THGT.LT.0.0) W2 = W2 + (0.0019812*THGT)
      IF (THGT.LT.0.0 .AND. W2.EQ.15.0 .AND. ZHGT.GE.THGT) GO TO 15
      IF (W2.LT.0.0) W2 = 0.0
      IF (W2.GT.30.0) W2 = 30.0
      GO TO 20
C
C  FOR STANDARD ATMOSPHERE, ADD BAROMETRIC HEIGHT TO GEOMETRIC HEIGHT TO
C  GET PRESSURE ALTITUDE; THEN, RETURN.
C
   15 ZTMP = W1
      ZPA = ZHGT + W10
      RETURN
C
C  CALCULATE GEOMETRIC HEIGHT ABOVE GROUND LEVEL W5
C
   20 W5 = ZHGT - THGT
C
C  CALCULATE GEOMETRIC HEIGHT OF TOP OF BOUNDARY LAYER
C
      W6 = THGT + 6561.68
C
C  CALCULATE TEMPERATURE FOR GEOMETRIC HEIGHT BELOW TERRAIN LEVEL
C
      IF (W5.GT.0.) GO TO 26
      ZTMP = TTMP
      GO TO 32
C
C  CALCULATE MAXIMUM OF INPUT HEIGHT VS TOP OF 6561.68 FOOT BOUNDARY LYR
C
   26 W4 = AMAX1(ZHGT,W6)
C
C  CALCULATE TEMPERATURE FOR INPUT HEIGHT ABOVE BOUNDARY LAYER, TEMP
C  AT THE TROPOPALSE AND HEIGHT OF THE TROPOPAUSE
C
      IF((W2-15.).GT.0.) GO TO 29
      W7 = -52.0 - (0.3*W2)
      W11 = 26246.718 + (656.16796*W2)
      ZTMP = AMAX1(W7,W2-(0.0019812*W4)) + W3*(0.0001905+0.0000762*W2)
      GO TO 30
   29 W7 = -39.0 - (W2*7./6.)
```

```
      W11 = 19685.038 + (1093.6132*W2)
      ZTMP = AMAX1(W7,W2-(0.0019812*W4)) + W3*(-0.0001397+0.00002963*W2)
C
C     CALCULATE TEMPERATURE WHEN WITHIN BOUNDARY LAYER BY INTERPOLATION
C     BETWEEN VALUES AT THE BASE AND TOP OF THE BOUNDARY LAYER
C
   30 IF (ZHGT.LT.W6) ZTMP = TTMP + ((W5/6561.68)*(ZTMP-TTMP))
C
C     CONVERT TEMPERATURES TO DEGREES K
C
      W18 = W7 + 273.15
   32 W8 = ZTMP + 273.15
      W9 = W1 + 273.15
      W12 = TTMP + 273.15
      W15 = W2 + 273.15
C
C     CALCULATE STANDARD ATMOSPHERE TEMPERATURE AT TOP OF TERRAIN LAYER
C
      W13 = 288.15 - (0.0019812*THGT)
C
C     CALCULATE AVERAGE STANDARD ATMOSPHERE TEMPERATURE BETWEEN SEA LVL AND
C     TOP OF TERRAIN LAYER
C
      W14 =        (288.15 + W13) / 2
C
C     CALCULATE STANDARD ATMOSPHERE TEMPERATURE AT TOP OF BOUNDARY LAYER
C
      W16 = W13 - 13.
C
C     CALCULATE TEMPERATURE AT TOP OF BOUNDARY LAYER
C
      W17 = W15 - (0.0019812*W6)
C
C     CALCULATE PRESSURE ALTITUDE ZPA BY ADDING BAROMETER HEIGHT TO THE
C     SUM OF THE PRESSURE ALTITUDE THICKNESSES FOR EACH SUCCESSIVE VERTICAL
C     LAYER
C
      ZPA = W10
C
C     CALCULATE THE PRESSURE ALTITUDE THICKNESS FOR A GIVEN LAYER BY MULTI-
C     PLYING THE LAYER GEOMETRIC THICKNESS BY THE RATIO WITHIN THE LAYER OF
C     THE AVERAGE STANDARD ATMOSPHERE TEMPERATURE TO THE AVERAGE AMBIENT
C     TEMPERATURE
C
C     CHECK IF TERRAIN HEIGHT AND GEOMETRIC HEIGHT BOTH ABOVE SEA LEVEL
C
   40 IF (THGT.GT.0.0.AND.ZHGT.GT.0.0) GO TO 60
C
C     CHECK IF TERRAIN HEIGHT AT OR BELOW SEA LEVEL AND IF GEOMETRIC HEIGHT
C     ABOVE SEA LEVEL
C
   41 IF (THGT.LE.0.0.AND.ZHGT.GT.0.0) GO TO 55
C
C     CHECK IF TERRAIN HEIGHT AND GEOMETRIC HEIGHT BOTH AT OR BELOW SEA LVL
C
   42 IF (THGT.LE.0.0.AND.ZHGT.LE.0.0) GO TO 48
C
```

```
C  SINCE TERRAIN HEIGHT IS ABOVE SEA LEVEL AND GEOMETRIC HEIGHT IS AT OR
C  BELOW SEA LEVEL, CALCULATE ZPA AND RETURN
C
   43 ZPA = ZPA + (ZHGT*(288.15-(0.0009906*ZHGT))/W12)
      RETURN
C
C  CALCULATE ZPA FOR BOUNDARY LAYER BELOW SEA LEVEL
C
   48 W19 = AMAX1(ZHGT,THGT)
      ZPA = ZPA + W19*(288.15-0.0009906*W19) /
     &            (W12+W8-THGT*(W17-W12)/6561.68) * 2
C
C  CHECK IF GEOMETRIC HEIGHT IS BELOW THE TERRAIN HEIGHT WITH BOTH THE
C  TERRAIN HEIGHT AND GEOMETRIC HEIGHT AT OR BELOW SEA LEVEL
C
      IF (W5.GT.0.) GO TO 51
C
C  CALCULATE ZPA FOR TERRAIN LAYER AND RETURN
C
      ZPA = ZPA + (W5*(W13-(0.0009906*W5))/W12)
   51 RETURN
C
C  SINCE THE TERRAIN HEIGHT IS AT OR BELOW SEA LEVEL AND THE GEOMETRIC
C  HEIGHT IS ABOVE BOTH SEA LEVEL AND THE TERRAIN, PRE-CORRECT FOR TERR
C  HEIGHT BELOW SEA LEVEL AND JUMP TO THE BOUNDARY LAYER CALCULATION
C
   65 ZPA = ZPA + THGT
      GO TO 70
C
C  CALCULATE ZPA FOR TERRAIN LAYER WHEN BOTH GEOMETRIC HEIGHT AND TERR
C  HEIGHT ARE ABOVE SEA LEVEL
C
   60 ZPA = ZPA+AMIN1(THGT,ZHGT)*(288.15-0.0009906*AMIN1(THGT,ZHGT))/W12
C
C  CHECK IF GEOMETRIC HEIGHT IS ABOVE HEIGHT OF TERRAIN
C
      IF (W5.LE.0.) RETURN
C
C  CALCULATE ZPA FOR BOUNDARY LAYER WHEN GEOMETRIC HEIGHT IS ABOVE SEA
C  LVL + ABV THE TERRAIN HEIGHT
C
   70 W20 = AMIN1(W5,6561.68)
      ZPA = ZPA + W20*(W13-0.0009906*W20)/(W12+W20*(W17-W12)/13123.36)
C
C  CHECK IF GEOMETRIC HEIGHT ABOVE BOUNDARY LAYER
C
   75 IF ((ZHGT-W6).LE.0.) RETURN
C
C  CALCULATE ZPA FOR TROPOSPHERIC LAYER FROM THE TOP OF THE BOUNDARY LYR
C  TO THE LOWER OF EITHER THE STANDARD ATMOSPHERE TROPOPAUSE OR THE
C  TROPOPAUSE
C
C  CHECK IF TROPOPAUSE HEIGHT IS LESS THAN STANDARD ATMOSPHERE TROPOPAUS
C
      IF ((W11-36089.237) .GT.0.) GO TO 90
C
C  CALCULATE ZPA FOR TROPOSPHERE BEWEEN THE BOUNDARY LAYER AND TROPOPAUS
```


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```
C
      W21 = AMIN1(ZHGT,W11)
      ZPA = ZPA + (W21-W6)*(W16+288.15-0.0019812*W21)
     &                  /(W17+W15-0.0019812*W21)
C
C  CHECK IF GEOMETRIC HEIGHT IS BELOW TROPOPAUSE
C
   81 IF ((ZHGT-W11).LE.0.) RETURN
C
C  CALCULATE ZPA FROM TROPOPAUSE TO STANDARD ATMOSPHERE TROPOPAUSE
C
      ZPA = ZPA +((AMIN1(ZHGT,36089.237)-W11)*(288.15-(0.0009906*(W11+
     &AMIN1(ZHGT,36089.237))))/W18)
C
C  CHECK IF GEOMETRIC HEIGHT IS ABOVE STANDARD ATMOSPHERE TROPOPAUSE
C
   84 IF ((ZHGT-36089.237).LE.0.) RETURN
C
C  CALCULATE ZPA FOR LAYER BETWEEN STANDARD ATMOSPHERE TROPOPAUSE AND
C  65616.796 FEET
C
      ZPA = ZPA + (AMIN1(ZHGT-36089.237,29527.558)*216.65/W18)
   87 GO TO 96
C
C  CALCULATE ZPA FOR TROPOSPHERE BETWEEN THE TOP OF THE BOUNDARY LAYER +
C  THE STANDARD ATMOSPHERE TROPOPAUSE
C
   90 W22 = AMIN1(ZHGT,36089.237)
      ZPA = ZPA +  (W22-W6)*(W16+288.15-0.0019812*W22)
     &                    /(W17+W15-0.0019812*W22)
C
C  CHECK IF GEOMETRIC HEIGHT IS BELOW STANDARD ATMOSPHERE TROPOPAUSE
C
   91 IF ((ZHGT-36089.237).LE.0.) RETURN
C
C  CALCULATE ZPA FOR LAYER BETWEEN STANDARD ATMOSPHERE TROPOPAUSE AND
C  TROPOPAUSE
C
      ZPA = ZPA +((AMIN1(ZHGT,W11)     -     36089.237)*216.65/(W15-
     &(0.0009906*(36089.237+AMIN1(ZHGT,W11)))))
C
C  CHECK IF GEOMETRIC HEIGHT IS ABOVE TROPOPAUSE
C
      IF ((ZHGT-W11).LE.0.) RETURN
C
C  CALCULATE ZPA FOR LAYER BETWEEN TROPOPAUSE AND 65616.796 FEET
C
      ZPA = ZPA +((AMIN1(ZHGT,   65616.796)-W11)*216.65/W18)
C
C  CHECK IF GEOMETRIC HEIGHT IS ABOVE 65616.796 FEET
C
   96 IF (W3.LE.0.) RETURN
C
C  CALCULATE ZPA FOR LAYER ABOVE 65616.796 FEET
C
      ZPA = ZPA + (W3*(216.65+W9)/(W18+W8))
   99 RETURN
      END
```

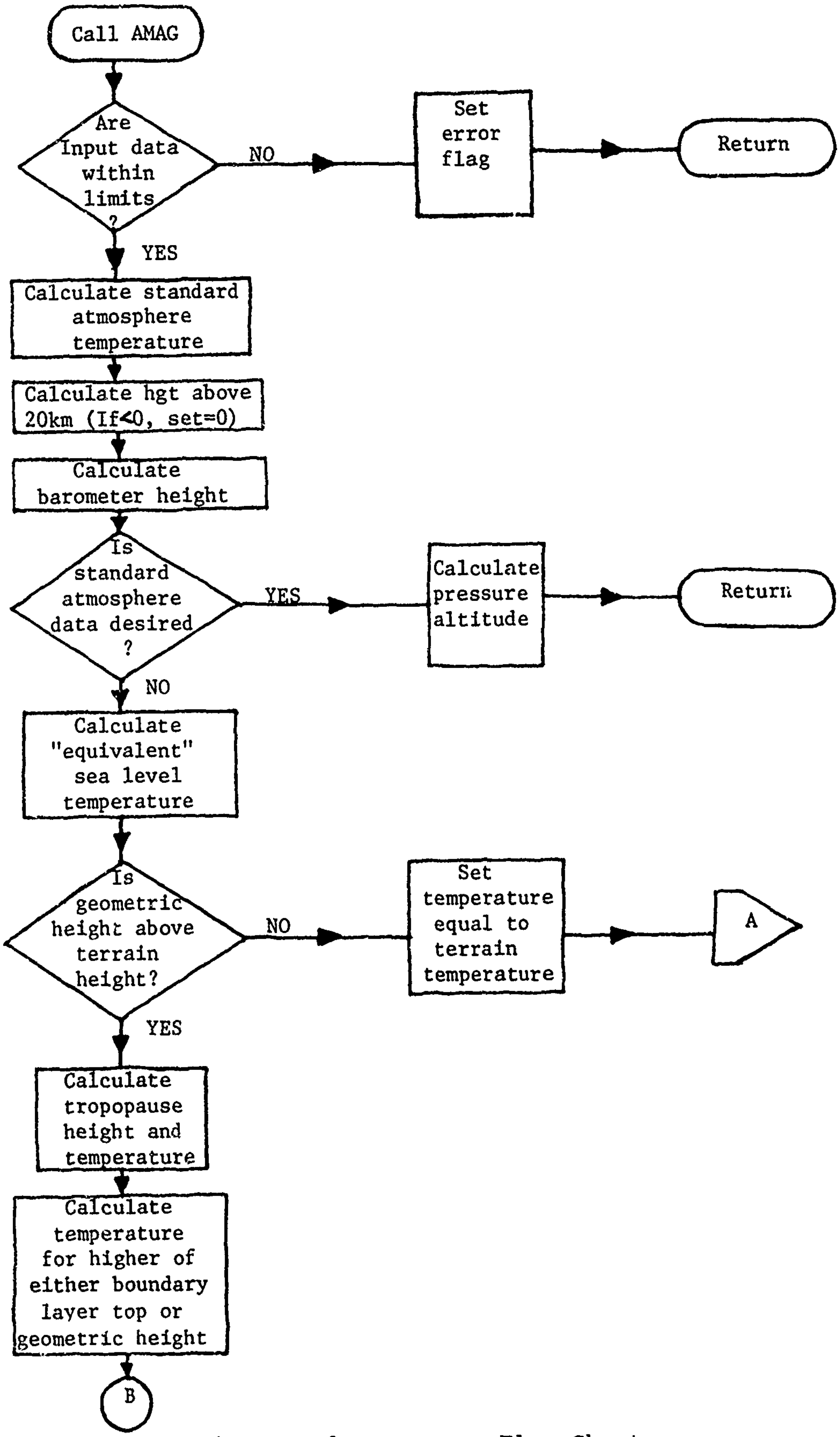

Figure A-1. Program Flow Chart

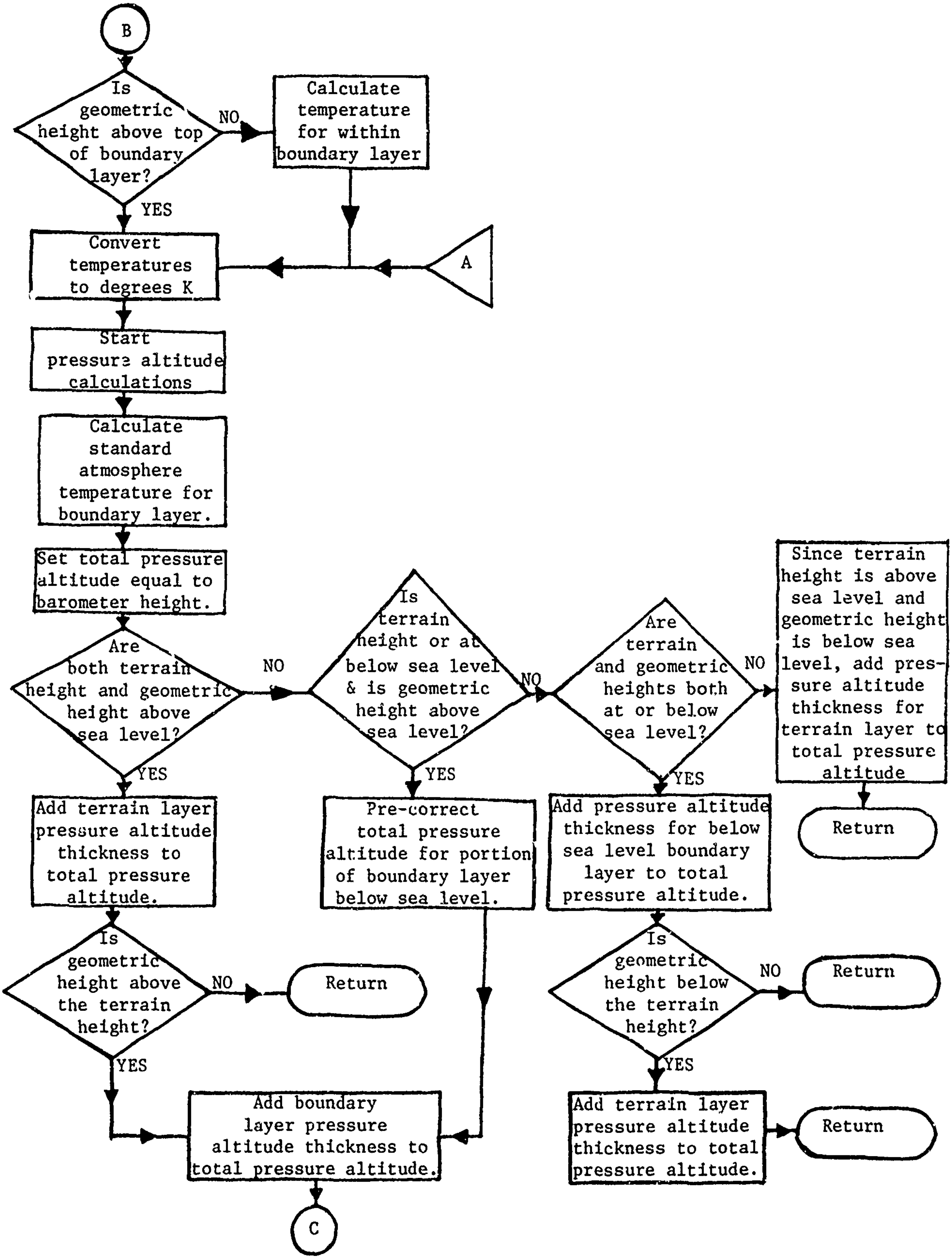

Figure A-1. Continued

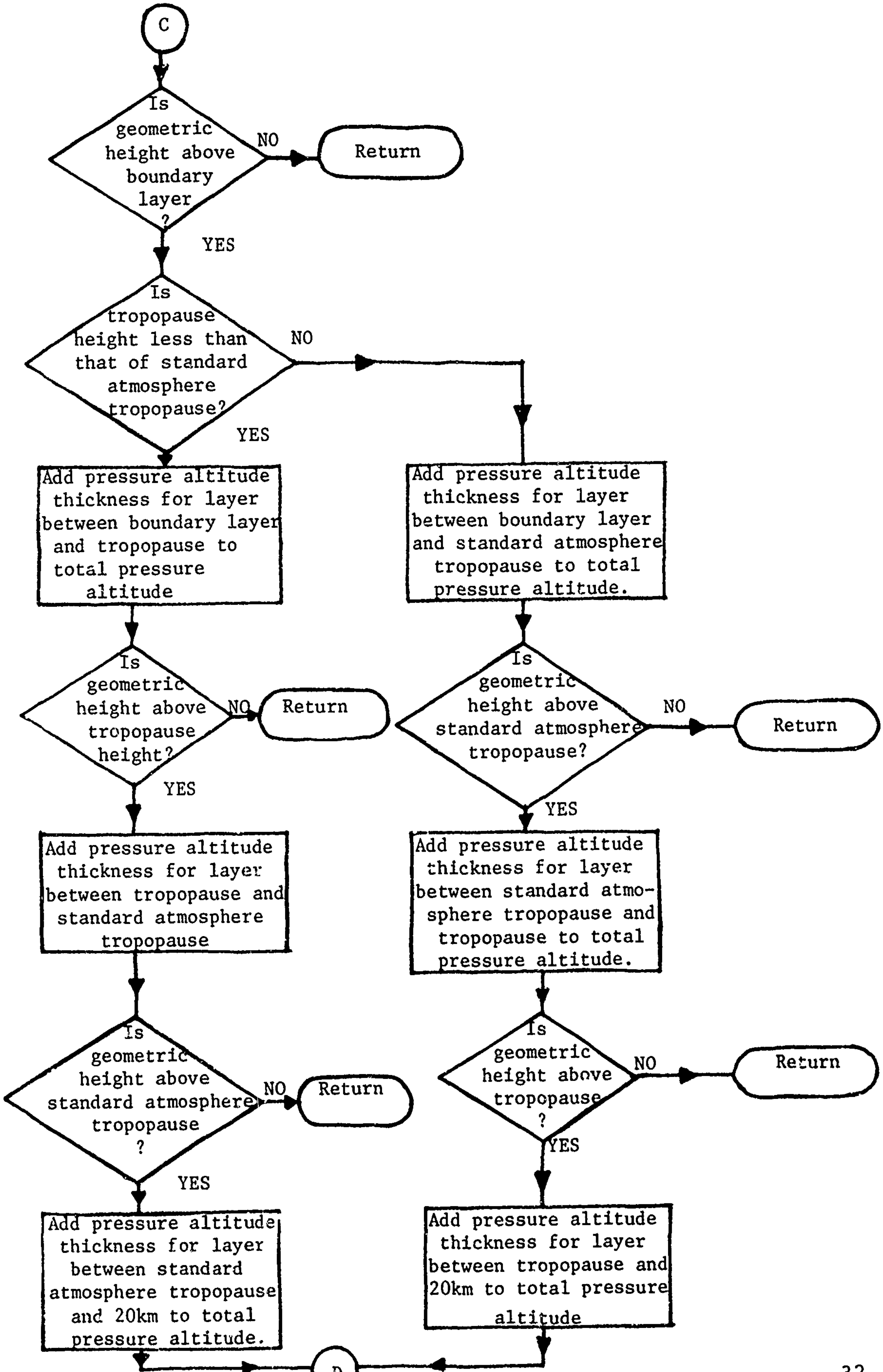

Figure A-1. Continued

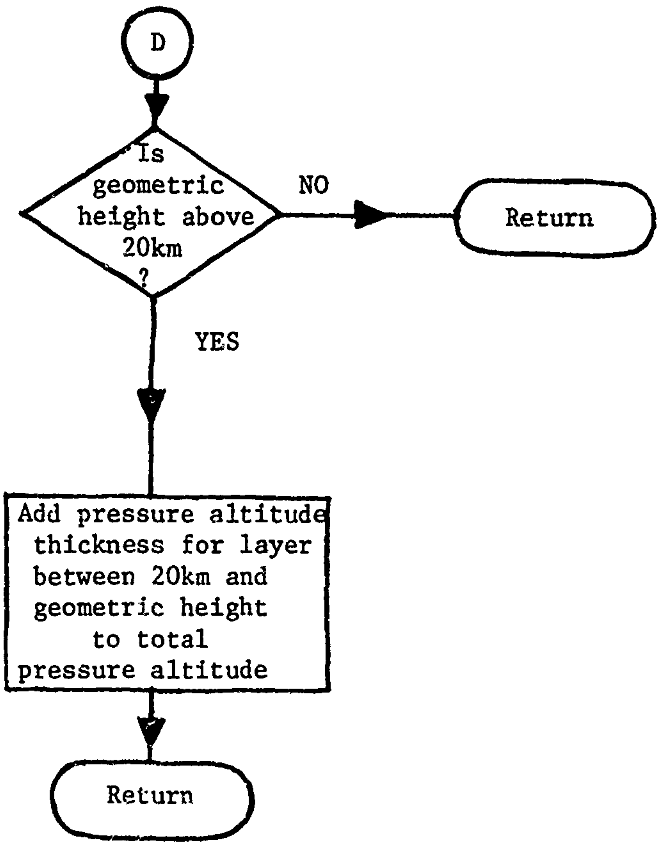

Figure A-1. Concluded

APPENDIX B

PROGRAM OUTPUT APPLICATIONS

Using the AMAG subroutine input values of altimeter setting ALSTG (In. Hg), geopotential height h (feet), terrain height h_g (feet) and ground virtual temperature T_g (°C) and output values of pressure altitude h_p (feet) and virtual temperature T_h (°C), several environmental parameters * of use to design engineers can be calculated as follows:

Standard Atmosphere Sea Level Value of

Temperature $T_{o_{st}}$ (°K) = 288.15

Pressure $P_{o_{st}}$ (lb/sq. foot) = 2116.217

Density $\rho_{o_{st}}$ (lb/cu. foot) = Ø.Ø76474

Speed of Sound $a_{o_{st}}$ (feet/second) = 1116.45

Coefficients of

Dynamic Viscosity μ_o (lb/foot·second) = $1.2Ø24213 \times 1Ø^{-5}$

Kinematic Viscosity η_o (sq. feet/second) = $Ø.1572284 \times 1Ø^{-3}$

Thermal Conductivity $k_{t,o}$ (BTU/foot·second·°R) = Ø.4Ø67468

Ambient Temperature T_h (°K)** = T_h (°C) + 273.15

Standard Atmosphere Temperature $T_{h_{p_{st}}}$ (°K)** =

288.15-MIN(71.5,Ø.ØØ19812*h_p)+Ø.ØØØ3Ø48*MAX(Ø.Ø,h_p-65616.796)

*See Table B-1 for conversion factors for metric to English units.

**In the AMAG model, $T_h = T_{h_p}$, $P_h = P_{h_p}$ and $\rho_h = \rho_{h_p}$ by definition.

$T_{h_{p_{st}}} \neq T_{h_{st}}$ unless $h=h_p$. However, $T_{h_{st}}$ normally is not a meaningful parameter.

Ambient Pressure P_h (lb/sq. foot)**

For $h_p \leq 36089.237$

$$= P_{o_{st}} \left(T_{o_{st}} / T_{h_{p_{st}}} \right)^{-5.25585}$$

$$\text{or } P_{o_{st}} \left(\frac{145442 - h_p}{145442} \right)^{5.25585}$$

For $36089.237 < h_p \leq 65616.796$

$$= 472.678 \exp \left(1.73456 - 0.0000480631 \, h_p \right)$$

For $h_p > 65616.796$

$$= 114.343 \left(216.65 / T_{h_{p_{st}}} \right)^{34.163}$$

$$\text{or } 114.343 \left(\frac{710794.}{645177.2 \div h_p} \right)^{34.163}$$

Ambient Density ρ_h (lbs/cu. foot)** $= 0.010413414 \left[P_h / T_h (°K) \right]$

Ambient Temperature Ratio $T_h / T_{o_{st}}$ $= T_h \; (°K) / 288.15$

Ambient Pressure Ratio δ_h $= P_h / 2116.217$

Ambient Density Ratio σ_h $= \rho_h / 0.76474$

Pressure Altitude Variation PAV (feet) $= h_p - h$

Speed of Sound a_h (feet/second) $= 65.77 \left[T_h (°K) \right]^{1/2}$

Mach Number M for a given speed V in feet/second $= V / a_h$ or $0.0152044 \, V / \left[T (°K) \right]^{1/2}$

Density Altitude h_d (feet)

For $h_p \leq 36089.237$

$$= 145442 \left[1 - \sigma_h^{0.0284389} \right]$$

For $36089.237 < h_p \leq 65616.796$

$$= 36089.237 - 20807.0 \log_e \left(\frac{\rho_h}{0.0227188} \right)$$

For $h_p > 65616.796$

$$= 710794 \left(\frac{0.0054981}{\rho_h} \right)^{0.0284389} - 645177.2$$

For $h_p < 10000$ feet, $\approx h_p + 120 \left[T_h \; (°K) - T_{h_{p_{st}}} \; (°K) \right]$

Total Temperature Ratio T_t/T $= 1.0 + 0.2M^2$

Free Stream Total Pressure to Ambient Pressure Ratio (Subsonic) $\frac{P_c}{P} = \left[1.0+0.2M^2\right]^{3.5}$

Total Pressure/Ambient Pressure Ratio $\frac{P_t}{P}$ (Supersonic) from Rayleigh Pitot Equation $= 166.92M^2/\left[7M^2-1.0\right]^{5/2}$

Incompressible Dynamic Pressure q (lb/sq. foot) $= 0.7P_hM^2$

or $1481.352\,\delta_h M^2$

or $0.00016183\left(\frac{P_hV^2}{T_h}\right)$

or $0.5\,\rho_h V^2$

Compressible Dynamic Pressure q_c (lb/sq. foot) $= P\left[\left(1.0+0.2M^2\right)^{3.5}-1.0\right]$

Equivalent Air Speed V_e (feet/second) $= V\sigma_h^{1/2}$

or $29.00751\,q^{1/2}$

Calibrated Air Speed V_c (feet/second)

For Subsonic Flow

$$= 2496.646\left[\left(1+\frac{q_c}{P_{o_{st}}}\right)^{3.5}-1.0\right]^{1/2}$$

For Supersonic Flow

$$= 984.66\left[\left(1+\frac{q_c}{P_{o_{st}}}\right)\left(1-\frac{1}{7M^2}\right)^{5/2}\right]^{1/2}$$

Coefficient of Thermal Conductivity $k_{t,h}$ (BTU/foot·second·°R) $= \frac{0.42563\left(T_h\right)^{3/2}}{T_h + 245.4 \times 10^{-(12/T_h)}}$

Coefficient of Dynamic Viscosity μ_h (lb/foot·second) $= \frac{0.97973\times10^{-6}\left(T_h\right)^{3/2}}{T_h+110.4}$

Coefficient of Kinematic Viscosity η_h (sq. feet/second) $= \mu_h/\rho_h$

TABLE B-1

CONVERSION FACTORS

To Convert From	To	Multiply By
Length		
Meter	foot	3.2808398 +0*
	U.S. statute mile	0.0621371 -2
	U.S. nautical mile	0.0539957 -2
Mass		
Gram	pound - mass	2.2046224 -3
	slug	0.0685217 -3
Volume		
Cubic meter	cubic inch	6.1023759 +4
	cubic foot	3.5314667 +1
Pressure		
Millibar	Pascal (Newton/sq. meter)	1.0000000 +2
	millimeter Hg.	7.5006151 -1
	inches Hg.	2.9529971 -2
	pound/sq. inch	1.4503768 -2
	pound/sq. foot	2.0885437 +0
Speed		
Meter/second	foot/second	3.2808398 +0
	kilometer/hour	3.5999997 +0
	mile/hour	2.2369363 +0
	knot	1.9438447 +0
Density		
Gram/cubic meter	pound/cu. foot	0.0624279 -3
	slug/cu. foot	0.0019403 -3
Temperature		
°Celsius (C)	°Fahrenheit (F)	°F = 1.8C +32
	°Kelvin (K)	°K = C+273.15
	°Rankine (R)	°R = 1.8K
Coefficient of Kinematic Viscosity (Sq. meter/sec)	sq. foot/sec	1.0763909 +1
Coefficient of Dynamic Viscosity (Newton·second/sq.m)	lb/foot·second	0.6719689 +0
Coefficient of Thermal Conductivity (Watts/meter·°K)	BTU/foot·second·°R	0.1606044 +3

NOTE: * Indicates the power of 10 for positioning the decimal point.

APPENDIX C
ATMOSPHERIC MOISTURE MODEL

In this Appendix, a method is outlined for generating vertical atmosphere moisture profiles which are consistent with any AMAG output virtual temperature - pressure altitude profiles.

The method involves a three-layer vertical moisture model based on an average relative humidity vertical profile derived from the U.S. Standard Atmosphere Supplements, 1966 (see Table E-1). It uses the AMAG output values of virtual temperature and pressure altitude and the AMAG input values of ground temperature, geometric height, terrain height and altimeter setting.

The first and lowest layer is the tropospheric layer bounded by mean sea level and the tropopause. For heights at and below mean sea level a constant 80% relative humidity is assumed. Above mean sea level the relative humidity is assumed to exponentially decrease with height. The terrain height is purposely ignored as a level of moisture discontinuity since surface moisture is not usually conserved over large changes in terrain height. High elevation locations tend to be much drier than low elevation locations. In this layer relative humidity is used as the moisture modeling parameter, rather than a parameter which specifies a certain amount of moisture such as specific humidity. This is done to avoid the possibility of encountering supersaturated conditions in calculations involving cold tropospheric temperatures. Relative humidity (RH) at any positive geometric altitude h for below the tropopause is calculated as follows:

$$RH\ (\%) = 80.\ \exp\ (-h/8\ \text{km}) \qquad \text{(C-1)}$$

The tropopause height h_t is calculated by the AMAG algorithm involving ground temperature as follows:

For ground temperatures T_g less than 0°C,

$$h_t = 26246.718\ \text{feet} = 8\ \text{km} \qquad \text{(C-2)}$$

For ground temperatures between 0°C and 15°C (T_g in °C),

$$h_t = 26246.718 + (656.16796 * T_g)\ \text{feet} \qquad \text{(C-3)}$$

For ground temperatures between 15°C and 30°C (T_g in °C),

$$h_t = 19685.038 + (1093.6132 * T_g)\ \text{feet} \qquad \text{(C-4)}$$

For ground temperatues T_g above 30°C,

$$h_t = 52493.434\ \text{feet} = 16\ \text{km} \qquad \text{(C-5)}$$

Since the tropopause tends to act as a cap on the upward propagation of moisture from the troposphere, the atmosphere above the tropopause, i.e., the stratosphere, is very dry. The discontinuity in moisture between the troposphere and stratosphere occurs at what is called the hygropause which is located at a height of one km above the tropopause. Above the hygropause and up to 100,000 feet, the amount of moisture is extremely small, i.e., a mixing ratio of one to three parts water vapor mass per million parts of dry air. Thus in this model we will assume a constant mixing ratio at all altitudes above the hygropause. From this assumption, the second and third layers of the moisture model can be defined.

The second moisture layer lies between the tropopause and the height of one km above the tropopause. The moisture modeling parameter used in this layer is the mixing ratio which is defined as the dimensionless ratio of the mass of water vapor to the mass of dry air. The term, saturation mixing ratio, is that value of the mixing ratio which corresponds to completely saturated air, i.e., 100% relative humidity. Thus relative humidity is defined as the percent ratio of the mixing ratio to the saturation mixing ratio. The mixing ratio at the tropopause is calculated from the tropopause temperature T_t, tropopause height h_t, tropopause relative humidity RH_t and tropopause pressure altitude PA_t. The tropopause temperature T_t is calculated from the ground temperature T_g as follows:

For ground temperatures T_g less than 0°C,

$$T_t = -52°C = 221.15°K \tag{C-6}$$

For ground temperatures between 0°C and 15°C (T_g in °C),

$$T_t = -52°C - (T_g * 0.3) \tag{C-7}$$

For ground temperatures between 15°C and 30°C (T_g in °C),

$$T_t = -39°C - (T_g * 7./6.) \tag{C-8}$$

For ground temperatures above 30°C,

$$T_t = -74°C = 199.15°K \tag{C-9}$$

The tropopause height h_t and relative humidity RH_t are calculated using the formulas given previously in this appendix. The tropopause pressure altitude PA_t can be calculated by the AMAG program

using the tropopause height h_t as the input geometric altitude along with the ground temperature, terrain height and altimeter setting inputs. From PA_t, the tropopause pressure P_t can be calculated using the formulas given in Appendix B. At this point the tropopause mixing ratio r_t can now be calculated by

$$r_t \left(\frac{gm}{kg}\right) \approx \left(\frac{38.0}{P_t}\right) * RH_t \times 10^{\left(\frac{7.5\, T_t}{T_t + 237.3}\right)} \qquad \text{(C-10)*}$$

where P_t = tropopause pressure in mb

RH_t = tropopause relative humidity in percent

T_t = tropopause temperature in °C

The mixing ratio at the hygropause and for the moisture model's third layer can now be determined. It is set equal to the smaller of either the tropopause mixing ratio r_t or the value of 0.003 gm/kg. For the first case, the mixing ratio at all geometric altitudes above the tropopause is set equal to the tropopause mixing ratio. For the second case, the mixing ratio r_h for geometric altitudes between the tropopause and the hygropause is calculated by logarithmic interpolation with height between the value of r_t and of 0.003 gm/kg as follows:

$$\ln r_h \text{ (gm/kg)} = \left[h_t(\text{km}) - h(\text{km}) + 1\text{km}\right] * \left[\ln r_t(\text{gm/kg}) + 5.8088\right] - 5.8088 \qquad \text{(C-11)}$$

Several relationships exist between relative humidity, mixing ratio, virtual temperature and temperature. For geometric height below the tropopause, the temperature T can be estimated from the AMAG output virtual temperature T_v by

$$T\ (°C) \approx T_v\ (°C) - 10^{\left[(T_v - 14)/38\right]} \qquad \text{(C-12)}$$

This approximation is necessary for T_v values above -25°C. For values of T_v less than -25°C, the second term is negligible and $T \approx T_v$. The approximation avoids solving a complex exponential equation and allows the direct calculation of mixing ratio r_h for any given height h from the temperature, pressure altitude and relative humidity by the following equation:

$$r_h\left(\frac{gm}{kg}\right) \approx 38.0 * RH_h * 10^{\left(\frac{7.5\,T_h}{T_h + 237.3}\right)} \Big/ P_h \qquad \text{(C-13)*}$$

where RH_h = relative humidity in percent

T_h = temperature in °C

P_h = pressure in mb as calculated from the pressure altitude using equations given in Appendix B

Once r_h is known, then a more accurate value of T_h can be calculated from T_v.

$$T_h(°K) = T_{v_h}\ (°K) * \left[1 - .000609 r_h\left(\frac{gm}{kg}\right)\right] \qquad \text{(C-14)}$$

In addition, the mixing ratio as approximated above is equal to the specific humidity which is defined as the ratio of the mass of water vapor to the mass of moist air containing the vapor. Absolute humidity which is simply the density of the water vapor can be calculated as follows:

$$\rho_{v_h}\left(\frac{gm}{m^3}\right) = r_h\left(\frac{gm}{kg}\right) * \rho_{d_h}\left(\frac{gm}{m^3}\right) * 10^{-3} \qquad \text{(C-15)}$$

where r_h = mixing ratio

ρ_{d_h} = dry air density as computed from equations for ambient density given in Appendix B.

Example moisture profiles are provided in Table C-1.

The tropospheric moisture profile calculated by this model can be made drier or wetter simply by adjusting the mean sea level 80% relative humidity value to lower or higher values respectively. However, it is not recommended that values of less than 30% be used.

*Equations C-10 and C-13 were derived from Tetens' empirical formula for saturation vapor pressure over water. In this appendix all formulas and calculations were based on saturation over water. To make calculations valid for saturation over ice, replace the constants, 7.5 and 237.3, by 9.5 and 265.5 respectively.

TABLE C-1

MOISTURE PROFILES

Geopotential Altitude Above M.S.L. (km)	COLD DAY*		HOT DAY*	
	Absolute Humidity (gm/m^3)	Virtual Temperature (°C)	Absolute Humidity (gm/m^3)	Virtual Temperature (°C)
0	2.66+0**	-5.0	22.47+0**	33.0
1	1.76+0	-9.0	15.39+0	25.0
2	1.15+0	-13.0	9.47+0	17.0
3	6.05-1	-19.5	6.09+0	10.5
4	3.08-1	-26.0	3.81+0	4.0
5	1.51-1	-32.5	2.21+0	-2.5
6	7.16-2	-39.0	1.42+0	-9.0
7	3.21-2	-45.5	7.83-1	-15.5
8	1.38-2	-52.0	4.34-1	-22.0
9	1.34-3	-52.0	2.32-1	-28.5
10	1.14-3	-52.0	1.19-1	-35.0
11	9.76-4	-52.0	5.89-2	-41.5
12	8.65-4	-52.0	2.78-2	-48.0
13	7.17-4	-52.0	1.24-2	-54.5
14	6.14-4	-52.0	5.26-3	-61.0
15	5.26-4	-52.0	2.10-3	-67.5
16	4.51-4	-52.0	7.81-4	-74.0
17	3.86-4	-52.0	5.00-4	-74.0
20	2.43-4	-52.0	2.99-4	-74.0
25	1.11-4	-48.88	1.22-4	-62.12
30	5.16-5	-45.75	5.29-5	-50.25
32	3.81-5	-44.50	3.82-5	-44.50

* Zero terrain height and 29.92 altimeter setting is assumed.

** Indicates the power of 10 for positioning the decimal point.

APPENDIX D
ATMOSPHERIC WIND MODEL

In this appendix, a method is outlined for generating vertical atmospheric wind profiles which are consistent with any AMAG output virtual temperature-pressure altitude profiles.

The method involves a six-layer model of an idealized steady-state scalar wind speed profile. It uses the AMAG input values of geometric altitude, terrain height and ground temperature and a user-specified value of the ground wind speed. This wind model is terrain following such that below the terrain height, the wind speed is set to zero and that above the terrain height, there is a one-km thick boundary layer in which the wind speed increases exponentially with height to a value of one and one-half times the ground wind speed at the top of the boundary layer. Above the boundary layer, the wind speed increases with height to a maximum at the height of the jet stream. The height of the maximum wind or jet stream is a linear function of the height of the tropopause and varies from 8 km to 14 km. The maximum wind speed is set equal to six times the ground wind speed. Above the jet stream the wind speed decreases with height up to 20 km where a wind speed value of twice the ground wind speed is reached. Between 20 km and 23 km, the wind speed is held constant. Above 23 km the wind speed increases linearly at a fixed rate of 4m/sec per kilometer.

Wind speed can thus be calculated for any geometric height as a function of the ground wind speed, terrain height and tropopause height. The tropopause height is calculated from the ground temperature as in Appendix C.

Let V_h = wind speed at geometric altitude h

V_g = ground wind speed

V_J = maximum wind (jet) speed = $6V_g$

h_T = tropopause height

h_g = terrain (ground) height

h_J = jet stream height

then for $h < h_g$

$$V_h = 0 \qquad \text{(D-1)}$$

for $h_g \leq h < (h_g + 1\,\text{km})$

$$V_h = V_g \exp\left[.4 * (h-h_g)\ \text{km}^{-1}\right] \qquad \text{(D-2)}$$

for $(h_g + 1\ \text{km}) \leq h \leq h_J$

$$h_J = 0.75h_T + 2\ \text{km} \qquad \text{(D-3)}$$

$$V_h = 6V_g \left[\frac{(h_J - h_g - 1)^2}{(h_J - h_g - 1)^2 + 3\,(h_J - h)^2}\right] \qquad \text{(D-4)}$$

for $h_J < h \leq 20$ km

$$V_h = 6V_g \left[\frac{(20\ \text{km} - h_J)^2}{(20\text{km} - h_J)^2 + 2(h - h_J)^2}\right] \qquad \text{(D-5)}$$

for 20 km $< h <$ 23 km

$$V_h = 2V_g \qquad \text{(D-6)}$$

for 23 km $\leq h <$ 32 km

$$V_h = 2V_g + 4\left(\frac{\text{m}}{\text{sec}\cdot\text{km}}\right) * (h - 23\ \text{km}) \qquad \text{(D-7)}$$

Example wind profiles are provided in Figure D-1.

Since this wind model represents only idealized steady-state scalar wind conditions, typical of mid latitude locations, its application should be limited to preliminary design investigations. The wind profiles generated with this model are approximately 90 percentile envelopes without considering gust factors, wind shear or wind direction. For more advanced design work for specific operational capabilities at specific locations, vector synthetic wind profiles based on detailed data from such locations should be used (See Ref. 3, Chap. 8). If a wind direction is needed for convenience sake, it should be assumed to be towards the east as is typical of the mid latitude westerlies, i.e., a wind direction of 270°. This value of 270° can vary slightly from 240° to 300° if northerly or southerly wind components are required. The wind direction variation with height cannot normally be generalized but

in the mid latitude westerlies, wind direction tends to turn clockwise with height between the boundary layer and the height of the maximum wind. Lastly if a wind profile with a given maximum wind (jet) value is desired then the input ground wind speed should be set equal to one-sixth of that value.

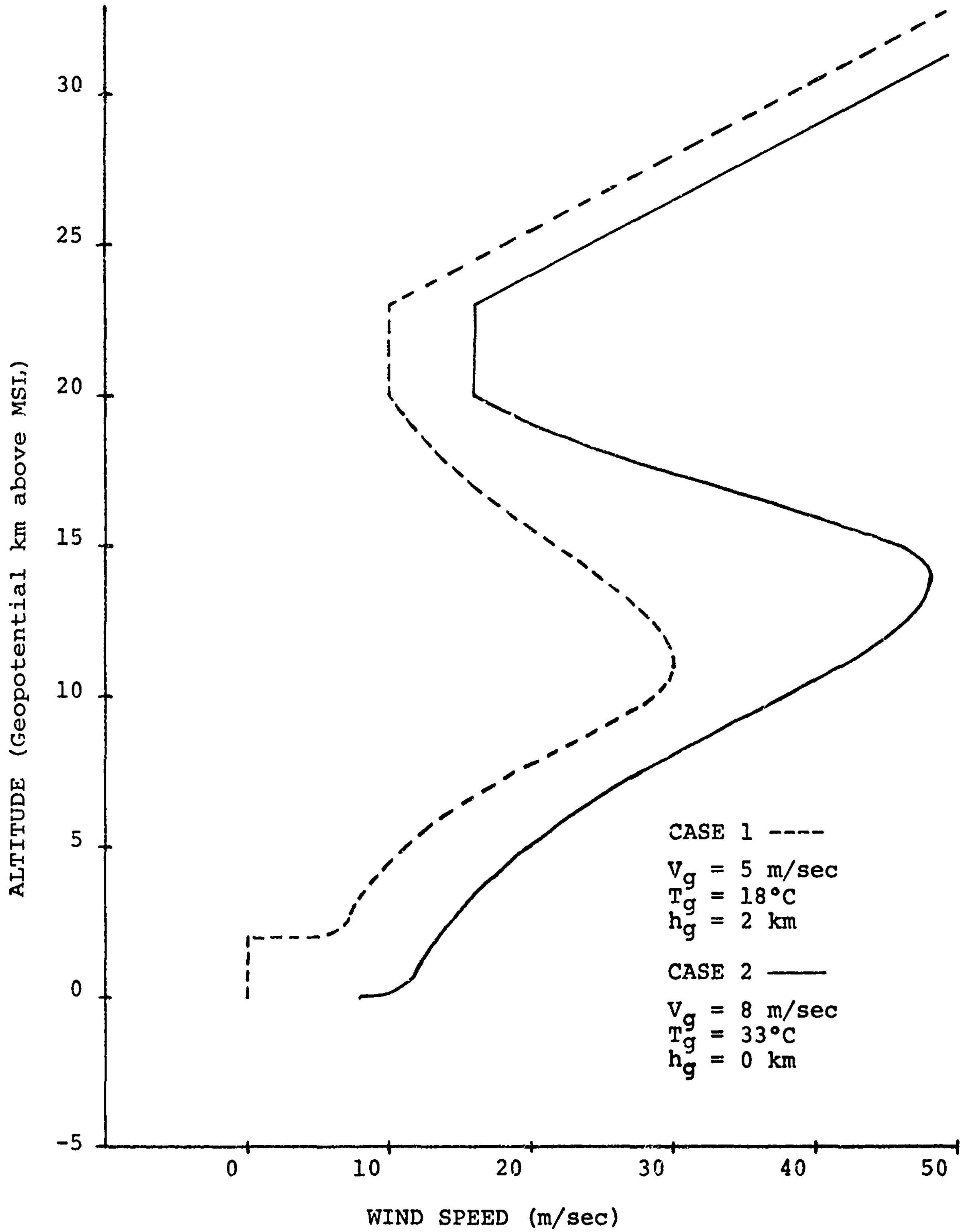

Figure D-1. Example Wind Speed Profiles

APPENDIX E
STANDARD ATMOSPHERES*

1. INTRODUCTION

Numerous problems in physics and engineering are sensitive to the state of the atmosphere. For example, aerodynamic problems are density and temperature dependent; refraction problems are dependent on density and water vapor concentration; and radiation transport problems are very sensitive to the concentrations of molecular species in the atmosphere.

In order to allow investigators to normalize the solutions of these and other problems to common atmospheric conditions, various standard atmospheres have been developed. In general, they represent an idealized model of the mean of a large number of atmospheric measurements. As our ability to accurately measure the atmospheric parameters of interest has developed, the standards have changed somewhat. Since a large number of measurements of the lower few kilometers of the atmosphere have been available for many years, standards there have changed little, if any, for the last 20 years or so. However, as radiosondes have been improved and other techniques have become available, measurements have been made to higher and higher altitudes. It is at these higher altitudes that most of the recent changes have been seen.

2. DEFINITIONS

At this point, it is necessary that we develop a common vocabulary for the discussions to follow. The following are definitions commonly accepted by atmospheric scientists:

a. Standard Atmosphere: A hypothetical vertical distribution of atmospheric temperature, pressure, and density which, by national or international agreement, is taken to be representative of the atmosphere for mean annual conditions at 45°N latitude. The air is assumed to obey the perfect gas law and the hydrostatic equation. It is further assumed that the air is dry and that the acceleration of gravity does not change with height.

*This Appendix is an updated extraction from program documentation for the FTD Standard Atmospheric written by Capt John D. Mill of the FTD Staff Meteorology Office (FTD/WE) in 1975.

b. <u>Model Atmosphere</u>: Any theoretical representation of the atmosphere. A model atmosphere does not have the force of law or international agreement.

c. <u>Reference Atmosphere</u>: A model atmosphere generally accepted as representing the atmosphere under certain conditions such as a particular season, or latitude or altitude interval. They are often moist atmospheres and may include such things as concentrations of molecular or atomic species. Many are intended to supplement atmospheres and therefore often have been called <u>supplementary atmospheres</u>, a term whose definition has now changed to refer to such things as ozone or humidity distributions.

d. <u>Temperature (Kinetic Temperature)</u>: A measure of the mean kinetic energy of the translational motion of molecules or atoms.

e. <u>Molecular-scale Temperature</u>: A fictional temperature derived from application of the perfect gas law under the assumption that the mean molecular weight of dry air is a constant. Below about 90 km, it is equal to the kinetic temperature.

f. <u>Virtual Temperature</u>: A fictional temperature of <u>moist</u> air derived from the application of the perfect gas law under the assumption that the mean molecular weight is that of dry air. This temperature is often used in reference atmospheres to facilitate calculations of density and density-dependent factors.

g. <u>Mean Molecular "Weight"</u>: The weighted average of the molecular masses of the atmospheric constituents, excluding water vapor (dry air). It has been defined on the carbon 12 scale of atomic mass as $2.89644 \times 10^{4}\ kg \cdot m^{-3}$.

h. <u>Geopotential Height</u>: The height of a given point in the atmosphere, relative to sea level, proportional to the potential energy of a unit mass at that height. It arises from the assumption of constant acceleration of gravity (see paragraph 1). It is defined as:

$$H = \frac{1}{g_0} \int_0^z g dz \qquad \text{(E-1)}$$

where: H = geopotential height

g_0 = acceleration of gravity at sea level

z = geometric height

g = acceleration of gravity at z.

(The standard for g_0 varies somewhat, depending on the model, but is most often taken as $9.80665 \text{ m}\cdot\text{sec}^{-2}$ at 45°N latitude.)

i. Altimeter Setting: The value of atmosphere pressure to which the scale of a pressure altimeter is set. This setting represents the pressure required to make the altimeter indicate zero altitude at mean sea level.

j. Pressure Altitude: The altitude, in the standard atmosphere, at which a given pressure will be observed. It is the indicated altitude of a pressure altimeter at an altimeter setting of 29.92 inches of mercury. A pressure altimeter converts atmosphere pressure into altitude using standard atmosphere pressure-height relations.

3. RESULTS

a. Proper Application of Standard Atmospheres:

Standard atmospheres are idealized representatives of mean conditions near 45°N latitude, primarily over land areas. As such, they do not accurately represent conditions at a given place or at a given time. The primary value of a standard atmosphere lies in its use as a reference point by which different calculations can be compared. The adoption of a standard assures that differences in results are due to elements of the experiment other than the atmospheric parameters. For this type of application, it does not matter a great deal what the exact standard is, but only that the same standard is used for all calculations which are to be compared.

On the other hand, there are many problems where atmospheric conditions are of central importance. Experimental data often need to be reduced to common environmental conditions (often a standard atmosphere), or the sensitivity of some value to changing conditions may need to be determined (often relative to a standard atmosphere). In these cases -- and others -- actual data at the time of the

experiment, specially developed model atmospheres, or one or more reference atmospheres are needed.

The degree of sophistication required in environmental data depends on the experiment (or numerical simulation) in a rather complicated manner. The basic point to be made is that a careful sensitivity analysis, error analysis, or theoretical investigation must be made in each case. It may, indeed, develop that a standard atmosphere is adequate, but this must be determined -- not assumed. It is often helpful to consult an environmental specialist when attempting to answer this question. The point of contact within ASD is the Staff Meteorology Office (WE). It is recommended that any proposed use of standard atmospheres or other environmental data be discussed with the staff meteorologist.

b. Available Standard and Reference Atmospheres:

In this section, the more widely used standard and reference atmospheres will be discussed briefly. There are a number of organizations which publish standard and reference atmospheres, and there is a rather complex interrelationship among them. Many of the same people sit on committees of more than one organization.

The abbreviations used for atmospheres of these organizations and an attempt to unscramble these relationships follow:

ARDC - Air Research and Development Command (now Air Force Systems Command). The earlier U.S. Standard Atmospheres were developed and published by ARDC.

ICAO - International Civil Aviation Organization. The ICAO does not develop its own atmospheres, but adopts those developed by other organizations, primarily COESA.

COESA - U.S. Committee on Extension to the Standard Atmosphere. COESA develops recommendations for revisions to U.S. standards and has been very influential in their adoption as international standards.

ISO - International Standards Organization. Coordinates the work of various national organizations, such as COESA, and adopts international standards.

CIRA - COSPAR* International Reference Atmospheres. COSPAR does not develop, recommend, or adopt standard atmospheres, but publishes a number of reference atmospheres, which, in general, begin at 25 to 30 kilometers and extend upward.

CIRA 1965 - Reference atmospheres, including latitudinal (10° intervals) and monthly variations from 25 to 80 kilometers and mean profiles for 25 to 500 kilometers and 110 to 2000 kilometers.

U.S. Standard Atmosphere Supplements, 1966 - (Hereafter referred to as the 1966 Supplements.) Moist reference atmospheres for winter and summer and five latitudes (15°N, 30°N, 45°N, 60°N, and 75°N), extending to 120 kilometers except at 70°N (30 km). Includes models of warm and cold stratospheric winter regimes for 60°N (to 80 km) and 75°N (to 30 km), and models from 120 to 1000 kilometers for various levels of solar-geomagnetic activity. It is very similar to the CIRA 1965, except at high latitudes, where the CIRA 1965 appears to be in better agreement with recent data.

CIRA 1972 - Revision of CIRA 1965. The latitudinal and monthly atmospheres were extended to 120 kilometers.

ISO 1972 - The latest international standard. It is identical to the 1962 Standard (U.S.) to 50 kilometers.

U.S. Standard Atmosphere, 1976 - Recently published, it is identical to the ISO 1972 to 80 kilometers and revises the 1962 Standard above 50 kilometers.

JACCHIA - A series of models extending above 120 kilometers, developed by Dr. L. Jacchia of the Smithsonian Astrophysical Observatory. Rather than tables of discrete reference atmospheres, they are algorithms for calculating models for various solar-geophysical conditions. In their various forms, they provided the basis of thermospheric reference atmospheres since 1965. (CIRA 1965 and 1972, 1966 Supplements.)

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*International Council of Scientific Unions Committee on Space Research

Figure E-1 represents, graphically, the relationships among the major standard atmospheres since 1952. The reference atmospheres are too numerous to include here, but some comparisons may be found in the U.S. Standard Atmosphere Supplements, 1966.

The following is a representative sample of the large number of models which have been developed in the past. There were standards prior to 1952, but they were essentially identical with more recent standards at low levels and are no longer used in their original form. In all cases, the more current edition replaced the older, which is no longer considered valid, though often it is unchanged.*

ICAO 1952 - A standard of temperature, pressure, and density to 11 kilometers. It has been extended by later models, but is unchanged* in that region.

ICAO 1954 - Extension of the ICAO 1952 to 20 kilometers. It is also unchanged* by subsequent standards.

ARDC 1956 - A U.S. standard which extended the ICAO to 500 kilometers.

COESA 1958 - A proposed revision of the ARDC 1956 to 300 kilometers. It was never adopted as a standard and was superceded by COESA 1962.

ARDC 1959 - A revision of the ARDC 1956 above 53 kilometers.

CIRA 1961 - The first COSPAR reference atmosphere. It is not a standard, and differs somewhat from the ICAO, ARDC, and COESA standards.

COESA 1962 - Proposed revision of the ARDC 1959 above 20 kilometers. It was adopted as the U.S. Standard Atmosphere, 1962.

U.S. Standard Atmosphere, 1962 - (Hereafter referred to as the 1962 Standard.) A revision of the ARDC 1959 above 20 kilometers, it includes a proposed extension of the ICAO to 32 kilometers. It also includes models from 120 to 700 kilometers for various levels of solar-geophysical activity.

*Although there have been slight revisions in some physical constants, the basic data is unchanged. The major difference is due to the redefinition of 0 C as 273.15°K vice 273.16°K. In this paragraph, "unchanged" is given this meaning.

c. Sources of Error

As pointed out a number of times above, most standard atmospheres are identical in the lower atmosphere. In general, all standards are identical up to 20 kilometers. When choosing a standard for use above these altitudes, it is important to recognize that a number of differences exist in this region, and care must be exercised if the results of calculations are to be compared with those done at different times or by different investigators. Where standards have been labeled as identical in this paper, one may assume that, conceptually, they will give identical results to at least three significant figures. There are minor differences such as the redefinition of the ice point on the Kelvin scale or the slightly different heights of some reference points, such as the stratopause.

Other sources of error involve the different definitions of height and temperature given in Paragraph 2 above. In many tables of standard atmospheres, heights are given in both geometric and geopotential meters (or feet) and care must be exercised when comparing results. The difference between these heights varies with both latitude and altitude and varies from zero at sea level to several kilometers in the thermosphere (above 120 km). For aeronautical purposes, the maximum error can be taken as 110 meters at 20 kilometers near the equator, or 65 meters at mid-latitude.

Above about 80 to 90 kilometers, one must be aware of the distinction between kinetic and molecular-scale temperature. Earlier models used the latter, while later models generally use the former. The error increases monotonically with increased altitude and can be as high as 1500°K in the thermosphere.

As mentioned previously, many reference atmospheres are moist models, and care must be used in the distinction between kinetic and virtual temperature at lower levels (below about 10 km). Although the difference can be as high as 6°K, for practical purposes, it seldom exceeds 3°K. It is important to note, for example, that the tabular values given in the U.S. Standard Atmosphere Supplements, 1966, are *virtual* temperatures which are derived from relative humidity values given in Table E-1.

The final major source of error is in the algorithms used to reproduce standard atmospheres for computer applications. Of course, care must be taken to account for the different heights and temperatures discussed above. There are two basic types of algorithms most often used. The first, application of the integral form of the hydrostatic equation to the temperature profile, is generally the most accurate, but is also the most time consuming unless data is requested in order of increasing altitude. The second general method involves a table lookup or interpolation on two parameters (e.g. temperature and pressure) and calculation of the third from the perfect gas law. To accurately interpolate on pressure or density, tabular values must be available at altitude intervals of from less than about 250 meters near the surface to 20 kilometers in the thermosphere. The obvious disadvantage of this technique is the large data arrays required. It is, however, generally faster than the first method. Round off error is generally not a problem on most machines unless some kind of polynomial curve fit is employed, or the first method is employed to great heights at relatively small intervals. In such cases, double precision variables should be used.

d. Meteorological Constants

Table E-2 is a summary of the primary constants adopted for the U.S. Standard Atmosphere, 1962. They are presented here as standards for meteorological calculations, to be used when reducing data from the standard to conditions compatible with other data. Some of them apply, strictly, only to 45°N latitude. Conditions at other latitudes can be obtained from supplementary atmospheres such as the U.S. Standard Atmosphere Supplements, 1966.

Supplementary or derived constants are given in Table E-3. Abundances of the most common atmospheric constituents of dry air are given in Table E-4. Other, less used, constants and equations are given in the U.S. Standard Atmosphere, 1962 and the U.S. Standard Atmosphere Supplements, 1966.

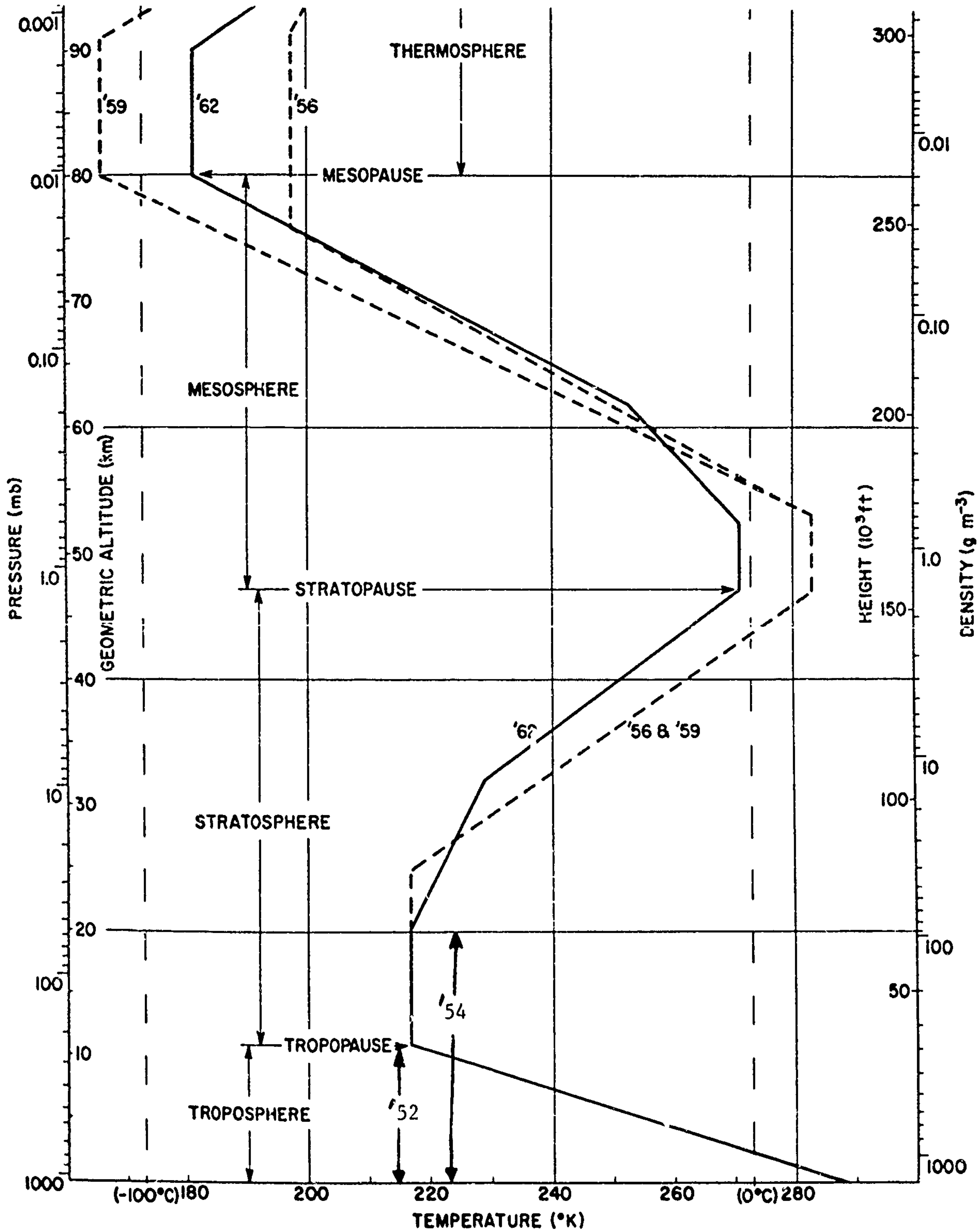

Figure E-1

Temperature-height profiles of the U.S. Standard Atmosphere, 1962, compared with the ARDC 1956 and 1959 and the ICAO 1952 and 1954. The COESA 1958 agrees closely with the ARDC 1956. There are additional small differences due to changes in some physical constants. Pressure and density scales refer to the 1962 standard. (After Valley, 1956)

TABLE E-1. MOISTURE PROPERTIES OF THE 1966 U.S. STANDARD ATMOSPHERE SUPPLEMENTS (after Valley, 1956)

Altitude (km) Geom	Geop	Temperature (°K)	Virtual Temp (°K)	Relative Humidity, %
		Tropical (15°N)		
0.000	0.000	299.65	302.588	75
1.002	1.000	293.65	295.893	75
2.005	2.000	287.65	289.336	75
2.256	2.250	286.15	287.717	75
2.507	2.500	286.95	287.743	35
4.012	4.000	276.90	277.363	35
6.020	6.000	263.50	263.709	35
8.029	8.000	250.10	250.172	30
10.039	10.000	236.70	236.717	20

Geom	Geop	Temp (°K) Jan	Temp (°K) July	Virtual Temp (°K) Jan	Virtual Temp (°K) July	Rel Hum (%) Jan	Rel Hum (%) July
		Subtropic (30°N)					
0.000	0.000	287.15	301.15	288.519	304.583	80	80
1.002	1.000	284.15	293.65	285.244	295.580	70	65
2.003	2.000	281.15	288.15	281.862	289.536	50	60
3.006	3.000	274.65	282.65	275.098	283.716	45	60
4.008	4.000	268.15	277.15	268.389	277.823	35	50
6.014	6.000	255.15	266.15	255.239	266.445	30	40
8.021	8.000	242.15	252.15	242.185	252.266	30	40
10.030	10.000	299.15	238.15	229.162	238.179	30	30
		Midlatitude (45°N)					
0.000	0.000	272.15	294.15	272.594	296.216	77	75
1.000	1.000	268.65	289.65	268.998	291.142	70	65
2.001	2.000	265.15	285.15	265.427	286.192	65	55
3.001	3.000	261.65	279.15	261.850	279.777	55	45
4.003	4.000	255.65	273.15	255.774	273.552	50	40
6.005	6.000	243.65	261.15	243.698	261.299	45	30
8.010	8.000	231.65	248.15	231.664	248.211	35	30
10.016	10.000	219.65	235.15	219.654	235.172	30	30
		Subarctic (60°N)					
0.000	0.000	257.15	287.15	257.285	288.449	80	75
0.999	1.000	259.15	281.75	259.311	282.685	70	70
1.998	2.000	255.95	276.35	256.089	277.062	70	70
2.998	3.000	252.75	270.95	252.861	271.447	65	65
3.497	3.500	251.15	268.25	251.245	#	60	--
3.997	4.000	247.75	265.55	247.824	265.889	60	60
4.998	5.000	240.95	260.15	#	260.376	--	55
5.998	6.000	234.15	253.15	234.170	253.277	50	50
8.000	8.000	220.55	239.15	220.550	239.185	40	40
10.003	10.000	------	225.15	-------	225.155	--	30

TABLE E-1. (CONCLUDED)

Altitude Geom	(km) Geop	Temp (°K) Jan	Temp (°K) July	Virtual Temp (°K) Jan	Virtual Temp (°K) July	Rel Hum (%) Jan	Rel Hum (%) July
Arctic (75°N)							
0.000	0.000	249.15	278.15	249.216	278.924	80	85
0.998	1.000	252.15	275.55	252.231	276.187	65	75
1.497	1.500	253.65	274.25	253.741	#	60	--
1.996	2.000	250.90	272.95	250.976	273.463	60	65
2.495	2.500	248.15	271.65	#	272.144	--	65
2.995	3.000	245.40	268.40	245.448	#	55	--
3.994	4.000	239.90	261.90	239.929	262.131	50	55
5.992	6.000	228.90	248.90	228.911	248.978	45	45
7.992	8.000	217.90	235.90	217.90	235.922	40	35
9.493	9.500	------	266.15	-------	226.158	--	30
9.993	10.000	------	226.65	-------	226.656	--	20

Not a virtual temperature breakpoint.

TABLE E-2

PRIMARY METEOROLOGICAL CONSTANTS USED IN DEVELOPING 1962 U.S. STANDARD ATMOSPHERE

Quantity	Symbol	Value	Error (1)	Units
Sea-level pressure (45°N)	P_0	1.01325×10^5	defined	$N \cdot m^{-2}$ (2)
Sea-level density (45°N)	ρ_0	1.22500×10^{-7}	5	$kg \cdot m^{-3}$
Sea-level temperature (45°N)	T_0	288.15 (15.00)	defined	K(°C)
Sea-level acceleration (45°N)	g_0	9.80665	defined	$m \cdot s^{-2}$
Ice-point temperature	T_i	273.15	defined	°K
Triple-point temperature (H_2O)	--	273.16	defined	°K
Mean collision diameter (air)	σ	3.65×10^{-8}	1	m
Avogadro's Number	N_A	6.02257×10^{26}	defined (3)	$kmole^{-1}$
Universal Gas constant	R	8.31432×10^3	4	$J \cdot kmole^{-1} \, {}^\circ K^{-1}$
Molecular weight of water	M_w	18.0153	1	$kg \cdot kmole^{-1}$ (4)

(1) Value is plus or minus the last digit given

(2) Ordinarily given as 1013.25 mb (millibars)

(3) Defined for purposes of these calculations, differs from SI value by .0004

(4) Based on $C^{12} = 12.0000$ $kg \cdot kmole^{-1}$

TABLE E-3

DERIVED METEOROLOGICAL CONSTANTS USED IN DEVELOPING 1962 U.S. STANDARD ATMOSPHERE

Quantity	Symbol	Value	Error	Units
Molecular weight of dry air	M_d	28.9644 (2)	defined	$kg \cdot kmole^{-1}$
Gas constant for dry air	R_d	2.87053×10^2	defined	$J \cdot kg^{-1} \cdot {}^\circ K^{-1}$
Specific heat of dry air, constant pressure	C_p	10.04686×10^2	(1)	$J \cdot kg^{-1} \cdot {}^\circ K^{-1}$
Specific heat of dry air, constant volume	C_v	7.17633×10^2	(1)	$J \cdot kg^{-1} \cdot {}^\circ K^{-1}$
Ratio of specific heats (C_p/C_v)	γ	1.4	defined	(dimensionless)

(1) Value is plus or minus the last digit given

(2) Based on $C^{12} = 12.0000\ kg \cdot kmole^{-1}$

TABLE E-4

NORMAL COMPOSITION OF CLEAN, DRY AIR NEAR SEA LEVEL

Gas/ Formula	By Volume	By Weight	Molecular Weight[(1)]
Nitrogen (N_2)	78.084±0.004%	75.5202±0.004%	28.0134
Oxygen (O_2)	20.946±0.002%	23.1404±0.002%	31.9988
Argon (A)	0.934±0.001%	1.288±0.001%	39.948
Carbon Dioxide (CO_2)	*0.033±0.001%	*0.050±0.002%	44.00995
Neon (Ne)	18.18±0.04ppm	12.67±0.04ppm	20.183
Helium (He)	5.24±0.04ppm	0.724±0.006ppm	4.0026
Methane (CH_4)	*2ppm	*1ppm	16.04303
Hydrogen (H_2)	0.5±0.05ppm	0.03±0.003ppm	2.01594
Nitrous Oxide (N_2O)	* 0.5±0.1ppm	*0.8±0.2 ppm	44.0128
Xenon (Xe)	0.087±0.001ppm	0.394±0.005ppm	131.30
Ozone (O_3)	*0 to 0.07ppm	*0 to 0.1ppm	47.9982
Sulfur Dioxide (SO_2)	*0 to 10.ppm	*0 to 20.ppm	64.0628
Nitrogen Dioxide (NO_2)	*0 to 0.02ppm	*0 to 0.03ppm	46.0055
Iodine (I_2)	*0 to 0.01ppm	*0 to 0.09ppm	253.8088

(1) based on $C^{12} = 12.0000\ kg \cdot kmole^{-1}$

(*) somewhat variable due to pollution

REFERENCES

1. H.B. Byers, General Meteorology, McGraw-Hill Book Co. Inc., New York, NY, 1959, Chapter 4.

2. R.E. Huschke, ed, Glossary of Meteorology, American Meteorological Society, Boston, MA, 1959, 638 pp.

3. J.W. Kaufman, ed, Terrestrial Environment (Climatic) Criteria for Guidelines for Use in Aerospace Vehicle Development, 1977 Revision, NASA Tech Memo 78118, Marshall Space Flight Center, AL, Nov 1977, 526 pp.

4. S.L. Valley, ed, Handbook of Geophysics and Space Environments, Air Force Cambridge Research Laboratories, 1965, Chapter 2.

5. R.C. Weast, ed, Handbook of Chemistry and Physics, 54th Ed., CRC Press, Cleveland, OH, 1973, pp F-186 to F-191.

6. Anonymous, Climatic Extremes for Military Equipment, MIL-STD-210A, Supt. of Doc., Washington, D.C. Aug 1957, 44 pp.

7. Anonymous, Climatic Extremes for Military Equipment, MIL-STD-210B, Supt. of Doc., Washington, D.C., Dec 1973, 72 pp.

8. Committee on Extension to the Standard Atmosphere, U.S. Standard Atmosphere, 1962, Government Printing Office, Washington, D.C., Dec 1962, 278 pp.

9. Committee on Extension to the Standard Atmosphere, U.S. Standard Atmosphere Supplements, 1966, Government Printing Office, Washington, D.C., 1967, 289 pp.

10. Committee on Extension to the Standard Atmosphere, U.S. Standard Atmosphere, 1976, Government Printing Office, Washington, D.C., Oct 1976, 227 pp.

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